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**55th ANNUAL FUZE CONFERENCE**

*“Fuzing’s Evolving Role in Smart Weapons”*

**Salt Lake City, UT**

**May 24 - 26, 2011**

Agenda (Brochure)  
On-Site Agenda

**WEDNESDAY, MAY 25, 2011**

**GENERAL SESSION  
SESSION I**

**A Soldiers Perspective**

- CSM Lance Lehr, US Army

**SESSION II  
DTRA S&T Strategy**

- Danny Hayles, Defense Threat Reduction Agency

**Navy S&T Strategy**

- Randall Cope, US Navy, NAVAIR China Lake

**OSD Perspective/ Fuze IPT**

- Charles Kelly, OUSD (AT&L) Land Warfare and Munitions

**Joint Fuze Technology Program**

- Lawrence Fan, US Navy, NSWC Indian Head Division

**Army Safety Approval Process**

- Chris Janow, Chief, Army Fuze Management Office

**Navy Safety Approval Process**

- Gabe Soto, Chairman, Fuze and Initiation System Technical Review Panel

**Air Force Safety Approval Process**

- Matt Bridge

**OPEN SESSIONS  
Session IIIA**

- Use of Charge Based Programmable Logic Devices to Perform Fuze Safety Functions, Robert Hubal, US Army, ARDEC
- Evolving Requirements for the Use of Logic Devices in the Implementation of Safety Features, John Hughes, US Navy, NAVAIR China Lake

- Ceramic Capacitor Failures & Lessons Learned, Patrick O'Malley, Sandia National Laboratories
- Enhanced Weapon Arming Safety by Controlled Accumulation of Arming Energy, Thomas Harward, Raytheon Missile Systems
- Pyro-MEMS, Renaud Lafont, NEXTER Munitions
- Universal Fuze Monitoring Test Systems, Jason Koonts, NSWCD, Computer Engineer
- Simple Optical Sensors for Firing Tests, Michael Connolly, US Army, AMRDEC
- Scalable Software Evaluation Methodology and Tools, Jeffrey Fornoff, US Army, ARDEC
- FIPS 140-2 Tamper Detection to protect Fuze Technology, John Ambrose, Mixed Signal Integration
- Void Sensing Fuze Product (VSF) Improvement Program, Transition of German Technology to Meet American Warfighter Needs, Dale Spencer, Kaman Precision Products

**THURSDAY, MAY 26, 2011**

**OPEN SESSIONS**

**Session IVA**

- Fuze Power - Quo Vadis?, Harald Wich, Diehl & Eagle Picher
- New Data Recorder for Gun Launch and Impact Test with Options for Built-in High G Accelerometers and Angular Rate Sensors, Stephen Pruitt, DTS
- Smart Materials for Fuzing, Dr. Daniel Peairs, L-3 Fuzing & Ordnance Systems
- Generation and Measurement of Long Duration High-g Acceleration Profiles, Siegfried Nau, Fraunhofer Ernst-Mach-Institut
- Development of a new MEMS High-g Accelerometer, Robert Kuells, Fraunhofer Ernst-Mach-Institut
- Course Correction Fuze - Integration Technologies, Max Perrin, JUNGHANS Microtec GmbH
- MK419 Mod 1 Multi-Function Fuze Product Improvement Program, Richard Chapman, US Navy, NSWC Dahlgren Division
- Fuze for Tiger Helicopter Rocket - Inductive Setting and Motor Ignition, Max Perrin, JUNGHANS Microtec
- Multifunction Fuze Capability Against High Speed Mobile Water Attack Craft, James Ring, ATK

# ***55<sup>th</sup> Annual Fuze Conference***

**May 24-26, 2011  
Grand America Hotel  
Salt Lake City, UT**

## **May 25, 2011 - General Session (AM)**

### **Session I**

- ☐ **8:00** Introduction/Admin Remarks – Dr. Barry Neyer
- ☐ **8:05** A Soldier's Perspective – CSM Lance Lehr, USA

### **Session II**

**(Chair: Eric Roach, Asst: Dr. Barry Neyer)**

- ☐ **8:40** DTRA Overview – Danny Hayles
- ☐ **9:00** Navy S&T Strategy – Randall Cope
- ☐ **9:20** Air Force S&T Strategy – Tim Tobik
- ☐ **9:40** Break
- ☐ **10:00** OSD Perspective/Fuze IPT – Charles Kelly
- ☐ **10:15** Joint Fuze Technology Program – Lawrence Fan
- ☐ **10:30** Army Safety Approval Process – Chris Janow
- ☐ **11:00** Navy Safety Approval Process – Gabe Soto
- ☐ **11:30** Air Force Safety Approval Process – Matt Bridge
- ☐ **11:50** Harry Diamond Fuzing Excellence Award Ceremony
- ☐ **12:00** Lunch



## **May 25, 2011 - OPEN Session (PM)**

### **Session IIIA**      **(Chair: Ed Cooper, Asst: Dave Lawson)**

- ☐ **1:00**      Use of Charge Based Programmable Logic... – R. Hubal
- ☐ **1:20**      Evolving Requirements for the Use of Logic... – J. Hughes
- ☐ **1:40**      40mm MEMS Fuze Integration Update – C. Robinson
- ☐ **2:00**      Ceramic Capacitor Failures & Lessons... – P. O'Malley
- ☐ **2:20**      Enhanced Weapon Arming Safety by... – T. Harward
- ☐ **2:40**      ~~Developments in Target Detection Device... – G. Buzzard~~
- ☐ **3:00**      Break
- ☐ **3:20**      Pyro-MEMS – R. Lafont
- ☐ **3:40**      Universal Fuze Monitoring Test System – J. Koonts
- ☐ **4:00**      Simple Optical Sensors for Firing Tests – M. Connolly
- ☐ **4:20**      Scalable Software Evaluation Methodology... – J. Fornoff
- ☐ **4:40**      FIPS 140-2 Tamper Detection to Protect... – J. Ambrose
- ☐ **5:00**      Void Sensing Fuze Product (VSF)... – D. Spencer/Dr. Muthig
- ☐ **5:30**      Grand Reception

## **May 26, 2011 - OPEN Session (AM)**

### **Session IVA**

**(Chair: Eric Roach, Asst: Lawrence Fan)**

- ☐ **8:00** Fuze Power – Quo Vadis? – H. Wich
- ☐ **8:20** New Data Recorder for Gun Launch and... – S. Pruitt
- ☐ **8:40** Smart Materials for Fuzing – Dr. D. Peairs
- ☐ **9:00** Generation and Measurement of Long... – S. Nau
- ☐ **9:20** Development of a new MEMS High-G Acc... – R. Kulls
- ☐ **9:40** OPEN
- ☐ **10:00** Break
- ☐ **10:20** Course Correction Fuze – Integration Tech... – M. Perrin
- ☐ **10:40** MK419 Mod 1 Multi-Function Fuze Prod... – R. Chapman
- ☐ **11:00** Fuze for Tiger Helicopter Rocket-Inductive... – M. Perrin
- ☐ **11:20** Multifunction Fuze Capability Against High... – J. Ring
- ☐ **11:40** ~~TDW's 2-inch Full Electronic Void Sens... – Dr. H. Muthig~~
- ☐ **12:00** Open Session Adjournment
- ☐ **12:05** Lunch

# 55<sup>TH</sup> ANNUAL FUZE CONFERENCE

## “Fuzing’s Evolving Role in Smart Weapons”



### PLAN TO ATTEND.....

- Participate in technical presentations on the latest advances in fuzing
- Learn about emerging trends in fuze technology
- Network with other professionals who share your interests

### SHOWCASE YOUR COMPANY.....

- Represent your company before a broad base of potential customers and partners
- Maximize your company’s visibility through sponsorship opportunities & table top displays

## HOTEL INFORMATION

### ***The Grand America***

555 South Main Street  
Salt Lake City, Utah 84111

### **Reservations:**

Tel: 1-800-304-8696

A limited block of rooms has been reserved at The Grand America and Little America (Gov Per Diem Rate offered here). To ensure the negotiated NDIA rate, please make your reservations early and ask for the NDIA room block - Industry or Government Per Diem. Rooms will not be held after Sunday, May 1, 2011 and may sell out before then. Rates are also subject to increase after this date. The government per diem rate is available only to active duty or civilian government employees.

### **Attire:**

The proper attire for this conference is business casual or military ACUs.

### **Inquiries:**

For more information, contact Mary Katherine Saladino, Meeting Planner at (703) 247-2540 or via e-mail at: [msaladino@ndia.org](mailto:msaladino@ndia.org).

## TUESDAY, MAY 24, 2011

3:00-6:30 pm - Onsite Registration

5:00-6:30 pm - Opening Reception

## WEDNESDAY, MAY 25, 2011

### GENERAL SESSION

#### Session I

7:00 am Onsite Registration/Continental Breakfast

8:00 am Introduction/Administrative Remarks  
*Barry Neyer, Chair, Fuze Division*  
*Chief Technology Officer, Defense, Excelitas Technologies Corp.*

8:05 am NDIA Opening Remarks  
*MG Barry Bates, Vice President, Operations*  
*National Defense Industrial Association*

8:10 am A Soldiers Perspective  
*CSM Lance Lehr, US Army*

#### Session II

**CHAIR: ERIC ROACH      ASSISTANT: BARRY NEYER**

8:40 am DTRA S&T Strategy  
*Danny Hayles, Defense Threat Reduction Agency*

9:00 am Navy S&T Strategy  
*Randall Cope, US Navy, NAVAIR China Lake*

9:20 am Air Force S&T Strategy  
*Tim Tobik, Chief, Fuze Branch, Air Force Research Laboratory*

9:40 am BREAK

10:00 am OSD Perspective/ Fuze IPT  
*Charles Kelly, OUSD (AT&L) Land Warfare and Munitions*

10:15 am Joint Fuze Technology Program  
*Lawrence Fan, US Navy, NSWC Indian Head Division*

10:30 am Army Safety Approval Process  
*Chris Janow, Chief, Army Fuze Management Office*

11:00 am Navy Safety Approval Process  
*Gabe Soto, Chairman, Fuze and Initiation System Technical Review Panel*

11:30 am Air Force Safety Approval Process  
*Mel Duval, Acting Chief, Air Force System Safety Office*

11:50 am Harry Diamond Fuzing Excellence Award Ceremony

12:00 pm LUNCH

**WEDNESDAY, MAY 25, 2011 (PM)****OPEN SESSIONS**Session IIIA**CHAIR: ED COOPER      ASSISTANT: DAVE LAWSON**

- 1:00 pm Use of Charge Based Programmable Logic Devices to Perform Fuze Safety Functions  
*Robert Hubal, US Army, ARDEC*
- 1:20 pm Evolving Requirements for the Use of Logic Devices in the Implementation of Safety Features  
*John Hughes, US Navy, NAVAIR China Lake*
- 1:40 pm Independence and Partitioning for Fuze Safety  
*Michael Connolly, US Army, AMRDEC*
- 2:00 pm Capacitor Failures: A Continuing Plague for Electronic Systems  
*Patrick O'Malley, Sandia National Laboratories*
- 2:20 pm Enhanced Weapon Arming Safety by Controlled Accumulation of Arming Energy  
*Thomas Harward, Raytheon Missile Systems*
- 2:40 pm Developments in Target Detection Device Clutter Discrimination Algorithms  
*Gary Buzzard, Thales*
- 3:00 pm BREAK
- 3:20 pm Pyro-MEMS  
*Renaud Lafont, NEXTER Munitions*
- 3:40 pm 40mm MEMS Fuze Integration Update  
*Charles Robinson, US Army, ARDEC*
- 4:00 pm Simple Optical Sensors for Firing Tests  
*Michael Connolly, US Army, AMRDEC*
- 4:20 pm Scalable Software Evaluation Methodology and Tools  
*Jeffrey Fornoff, US Army, ARDEC*
- 4:40 pm FIPS 140-2 Tamper Detection to protect Fuze Technology  
*John Ambrose, Mixed Signal Integration*
- 5:00 pm Void Sensing Fuze Product (VSF) Improvement Program, Transition of German Technology to Meet American Warfighter Needs  
*Dale Spencer, Kaman Precision Products*
- 5:20 pm Adjourned for the Day
- 5:30 pm - 7:00 pm Grand Reception

**US ONLY SESSIONS**Session IIIB**CHAIR: TOM BAGINSKI      ASSISTANT: FRAN MATTIA**

- 1:00 pm Piezoelectric Generation in the Fuze Environment  
*Dr. Daniel Peairs, L-3 Fuzing & Ordnance Systems*
- 1:20 pm FMCW Target Classification  
*Charles Overman, University of Florida Electronic Communications Lab*
- 1:40 pm Integrating Direct Write Technologies for Explosives Systems  
*Dr. Brian Fuchs, US Army, ARDEC*
- 2:00 pm Anti Tamper Technologies in Fuze Environments  
*Bobby Zienowicz, US Army, ARDEC & Stephen Redington, US Army, ARDEC*
- 2:20 pm Development of a Direct Write Exploding Foil Initiator  
*Dr. Ann Marie Petrock, US Army, ARDEC*
- 2:40 pm High Reliability Fuzing Architecture for Cluster Munitions  
*David Gudjohnsen, US Army, ARDEC*
- 3:00 pm BREAK
- 3:20 pm Enabling Technologies for Miniature Firing Systems  
*Charles Treu, NNSA Kansas City Plant*
- 3:40 pm System Integration of Miniature Fuze Technologies  
*Kenneth Jensen, NNSA Kansas City Plant*
- 4:00 pm A Compact MIL-STD-1901A Compliant Rocket Motor Initiator to Replace Current Initiators  
*Paul Moore, Excelitas Technologies Corp*
- 4:20 pm High Power & Energy Supercapacitors Fabricated with Inherently Conductive Polymers for Improved Performance  
*Hai-Long Nguyen, US Army, ARDEC*
- 4:40 pm Dual Load Exploding Foil Initiator Detonator  
*Don Warren, Excelitas Technologies Corp.*
- 5:00 pm High Energy and High Power Thermal Battery Options for Weapons Applications  
*Dr. David Swanson, Enersys Advanced Systems Inc.*
- 5:20 pm Adjourned for the Day
- 5:30 pm - 7:00 pm Grand Reception



## THURSDAY, MAY 26, 2011 (AM)

### REGISTRATION

7:00 am      Onsite Registration/Continental Breakfast

### OPEN SESSIONS

#### Session IVA

**CHAIR:** ERIC ROACH    **ASSISTANT:** LAWRENCE FAN

- 8:00 am    Fuze Power - Quo Vadis?  
*Harald Wich, Diehl & Eagle Picher*
- 8:20 am    New Data Recorder for Gun Launch and Impact Test with Options for Built-in High G Accelerometers and Angular Rate Sensors  
*Stephen Pruitt, DTS*
- 8:40 am    Smart Materials for Fuzing  
*Dr. Daniel Peairs, L-3 Fuzing & Ordnance Systems*
- 9:00 am    Generation and Measurement of Long Duration High-g Acceleration Profiles  
*Siegfried Nau, Fraunhofer Ernst-Mach-Institut*
- 9:20 am    Development of a new MEMS High-g Accelerometer  
*Robert Kuells, Fraunhofer Ernst-Mach-Institut*
- 9:40 am    Advanced Rapid Prototype Platform for Fuze Designers  
*Tracy Becker, National Nanotechnology Manufacturing Center, Inc.*
- 10:00 am    BREAK
- 10:20 am    Course Correction Fuze - Integration Technologies  
*Max Perrin, JUNGHANS Microtec GmbH*
- 10:40 am    MK419 Mod 1 Multi-Function Fuze Product Improvement Program  
*Richard Chapman, US Navy, NSWC Dahlgren Division*
- 11:00 am    Fuze for Tiger Helicopter Rocket - Inductive Setting and Motor Ignition  
*Max Perrin, JUNGHANS Microtec*
- 11:20 am    Multifunction Fuze Capability Against High Speed Mobile Water Attack Craft  
*James Ring, ATK*
- 11:40 am    TDW's 2-inch Full Electronic Void Sensing Penetrator Fuze is Ready  
*Dr. Helmut Muthig, TDW GmbH*
- 12:00 pm    LUNCH

### US ONLY SESSIONS

#### Session IVB

**CHAIR:** CURT POWELL      **ASSISTANT:** DON SHUTT

- 8:00 am    The Fuze Environment of Boosted Penetrators  
*Dr. Jason Foley, US Air Force, AFRL Munitions Directorate*
- 8:20 am    Hard Target Void Sensing Fuze (HTVSF) Test Results  
*Jeremy Oligmueller, ATK*
- 8:40 am    Sub-Scale Fuze Survivability Protocol for Hard Target Fuzes  
*Stephen Szczepanski, US Air Force, AFRL Munitions Directorate*
- 9:00 am    Hardened Miniature Fuze Technology Progress  
*Jefferson Oliver, US Air Force, AFRL Munitions Directorate*
- 9:20 am    Mechanical Energy Propagation into Penetrating Weapon Fuzes  
*Dr. Jason Foley, US Air Force, AFRL Munitions Directorate*
- 9:40 am    Dynamic Impact Simulation of Deceleration Pulse for Layer Sensing Fuzes  
*Dr. Paul Glance, US Navy, NAVAIR China Lake*
- 10:00 am    BREAK
- 10:20 am    Robust Fuzewell Instrumentation System (RFIS)  
*Kenneth Williamson, US Air Force, AFRL Munitions Directorate*
- 10:40 am    Development of the Design-a-Shock Methodology  
*Dr. Janet Wolfson, US Air Force, AFRL Munitions Directorate*
- 11:00 am    Hard Target Void Sensing (HTVSF) Update  
*Keith Thomas, Thales*
- 11:20 am    Improving Fuze Environment Prediction During Hard Target Penetration Using A Coupled-Code Erosion Technique  
*Reid McKeown, US Navy, NSWC Indian Head Division*
- 11:40 am    Fuze Diagnostic Recording  
*Darren Wang, Sandia National Labs*
- 12:00 pm    LUNCH

## THURSDAY, MAY 26, 2011 (PM)

### US ONLY SESSION

#### Session VA

**CHAIR: DON SHUTT      ASSISTANT: BOB HERTLEIN**

- 1:00 pm A Low Voltage Command-Arm System for Distributed Fuzing  
*Mark Etheridge, US Army, AMRDEC*
- 1:20 pm Target Detection Device and ESAD Designs for a KE Active Protection System  
*Nicholas Cali, US Army, ARDEC*
- 1:40 pm Low-Cost Miniature Electronic Safe-Arm Device (ESAD)  
*Michael Haddon, US Navy, NAWC Weapons Division*
- 2:00 pm Side Mount Height of Burst Sensor for the Laser Joint Direct Attack Munition  
*Brian Miracle, L3 Fuzing & Ordnance Systems*
- 2:20 pm ATK Next Generation Proximity Sensor Test Results  
*Christopher Fuller, ATK*
- 2:40 pm Detonation Phenomena in Deposited Explosives at Sub-Millimeter Dimensions  
*Alexander Tappan, Sandia National Laboratories*
- 3:00 pm BREAK
- 3:20 pm Replaceable M213/228 Hand Grenade Electronic Fuze with Non-Inertial MEMS S&A  
*Ryan Knight, US Army, ARDEC*
- 3:40 pm Enhanced Performance of MEMS Electric Initiators  
*Daniel Pines, US Navy, NSWC Indian Head Division*
- 4:00 pm Nanoporous Energetic Silicon Initiators  
*Dr. Christopher Morris, US Army, Army Research Laboratory*
- 4:20 pm Micro-Scale Firetrain Explosive Inks Manufacturing Technology Development  
*Tim Hoang, US Army, ARDEC*
- 4:40 pm Wafer Level Packaging for High Aspect Ratio MEMS  
*Kevin Cochran, US Navy, NSWC Indian Head Division*
- 5:00 pm MEMS Safe and Arm – Facilitating Miniature Munitions  
*Dale Spencer, Kaman Precision Products*
- 5:20 pm Wrap- Up & Conference Adjourned  
*Don Shutt, ATK*

### US ONLY SESSION

#### Session VB

**CHAIR: BARRY NEYER      ASSISTANT: TIM TOBIK**

- 1:00 pm Thin Film Dielectric Breakdown Investigation for High Voltage Switch Applications  
*Bradley Hanna, US Navy, NSWC Dahlgren Division*
- 1:20 pm The Design of Low or Ultra Low Energy Exploding Foil Initiation Devices  
*Michael Meadows, Reynolds Systems Inc.*
- 1:40 pm The Use of Conventional Bridge Models to Predict Performance of Electrically Driven Flyers for EFI Devices  
*Edwin Wild, US Air Force, AFRL Munitions Directorate*
- 2:00 pm State-of-the-Art of Reliability Methodologies for Munitions Fuzes  
*John Deep, US Air Force, AFRL Munitions Directorate*
- 2:20 pm The Use of Conventional Bridge Models to Predict Performance of Electrically Driven Flyers for EFI Devices  
*Dr. Eric Welle, US Air Force, AFRL Munitions Directorate*
- 2:40 pm Characterization of Initiation Phenomena for the Purpose of Warhead Design  
*Dr. Eric Welle, US Air Force, AFRL Munitions Directorate*
- 3:00 pm BREAK
- 3:20 pm Piezoelectric Setback Generators for the 30mm STAR ATO Program  
*Alfredo Vazquez Carazo, Micromechatronics, Inc.*
- 3:40 pm Conformal Antennas for Weapon Sensors  
*Dennis Jones, Mustang Technology Group*
- 4:00 pm MEMS Retard and Impact Sensors  
*Walter Maurer, US Navy, NAVAIR China Lake*
- 4:20 pm Passive Planar Setback Switch for Gunned Applications  
*Scott Rauscher, US Army, ARDEC*
- 4:40 pm Low Cost Inertial Measurement Unit as Environment Sensor  
*Noah Desch, L-3 Fuzing & Ordnance Systems*
- 5:00 pm HARM (High-Aspect Ratio Metal)-MEMS Very Low-G Viscously-Damped Inertial Switches  
*Ryan Knight, US Army, ARDEC*
- 5:20 pm Wrap- Up & Conference Adjourned  
*Barry Neyer, Excelitas*

## Sponsorship Opportunities:

### Fitness Center Sponsor

**SOLD: Meggitt Sensing Systems**

Benefits:

- One complimentary symposium registration
- Placement of your company's logo in the agenda handouts
- Signage at NDIA registration desk on May 24, 2011
- Sponsor ribbon on badge

**Continental Breakfast Sponsor- Investment: \$5,000 per breakfast (One opportunities remaining)**

**1 SOLD: Kaman Precision Products**

Benefits:

- Two complimentary symposium registrations
- Placement of your company's logo in the agenda handouts and proceedings
- Signage outside the particular event sponsored
- Sponsor ribbon on badges

**Break Sponsor- Investment: \$4,000 per break (Two opportunities remaining)**

**2 SOLD: L-3**

Benefits:

- One complimentary conference registration
- Placement of your company's logo in the agenda handouts and proceedings
- Company description (250 words) in onsite agenda
- Signage outside the particular event sponsored
- Sponsor ribbon on badges

**Lunch Sponsor- Investment: \$6,000 per lunch (One opportunity remaining)**

**1 SOLD: DSE, Inc.**

Benefits:

- Three complimentary symposium registrations
- Company logo and link to your company on event web site
- Placement of your company's logo in the agenda handouts and proceedings
- Company description (300 words) in onsite agenda
- Signage outside the particular event sponsored
- Sponsor ribbon on badges

**Opening Reception Sponsor- Investment:**

**SOLD: Lockheed Martin**

Benefits:

- Three complimentary symposium registrations
- Company logo and link to your company on event web site
- Placement of your company's logo in the agenda handouts and proceedings
- Company description (300 words) in onsite agenda
- Company name on cocktail napkins at the reception



## Sponsorship Opportunities CONT.:

### Grand Reception Sponsor-

**SOLD: ATK**

Benefits:

- Four complimentary symposium registrations
- Company logo and link to your company on event web site
- Placement of your company's logo in the agenda handouts and proceedings
- Signage outside the particular event sponsored
- Opportunity to give a 10-minute company presentation at the reception
- Hosted bar and heavy hors d'ouvres for attendees
- Live musical entertainment provided
- Sponsor ribbon on badges

### Create Your Own Opportunity!

Many of the NDIA events offer category exclusive sponsorships to fit your budget. By enhancing your brand with a sponsorship at our events you'll build a stronger perception from the audience and stand out from the crowd. NDIA is open to custom sponsorship ideas.

## Table Top Display Opportunities:

Interested in displaying your company's information? Register for a 6' table top display at the 2011 Fuze Conference!

This 6' table top display will give you an opportunity to have extra exposure to the Fuzing community at the 55th Annual Conference.

The cost to display is \$750, registration form is on the next page.

\*Included in the table top display registration is one conference registration for the exhibit-display personnel to attend the 55th Annual Fuze Conference. This also include attendance at all of the event food functions.

### Hours of Operation:

#### Tuesday, May 24th

Set Up 2:00pm- 3:00pm  
3:00pm - 6:30pm

#### Wednesday, May 25th

7:00am - 8:00am

#### Wednesday, May 25th cont.

10:00am - 10:20am  
12:00pm - 1:00pm  
3:00pm - 3:20pm  
5:30pm - 7:00pm

#### Thursday, May 26th

7:00am - 8:00am  
10:00am - 10:20am  
12:00pm - 1:00pm  
3:00pm - 3:20pm

# GENERAL CONFERENCE INFORMATION

## ATTENDEE ROSTER:

An attendance roster will be available at the conference registration desk. In order for your name to appear in the roster, you must be registered for this event by May 6, 2011. An updated roster will NOT be printed after the conference.

## SPECIAL NEEDS:

NDIA supports the Americans with Disabilities Act of 1990. Attendees with special needs should call or email Mary Katherine Saladino, Meeting Planner at 703-247-2540 [msaladino@ndia.org](mailto:msaladino@ndia.org) by May 3, 2011.

## \*US ONLY SESSIONS:

Certificate for Attendance will be the process to verify citizenship to attend this year's US Only Sessions. Please download the form at : [www.ndia.org/meetings/1560](http://www.ndia.org/meetings/1560) under the red 'Agenda or Registration' tab and complete section I & II before submitting.

## QUESTIONS?

Please contact NDIA POC: Mary Katherine Saladino, Meeting Planner at (703) 247-2540 or via email at [msaladino@ndia.org](mailto:msaladino@ndia.org).

## REGISTRATION

**NOTE: THERE ARE TWO SEPARATE REGISTRATION PROCESSES. ONE FOR CONFERENCE REGISTRATION AND ONE IF YOU PLAN TO ATTEND US ONLY SESSIONS. YOU MUST COMPLETE THE CERTIFICATE FOR ATTENDANCE.**

**ADDITIONAL DETAILS AND FORMS CAN BE FOUND AT [WWW.NDIA.ORG/MEETINGS/1560](http://WWW.NDIA.ORG/MEETINGS/1560) UNDER THE RED REGISTRATION TAB.**

### ONLINE:

Our preferred method of registration is online. Please go to [www.ndia.org/meetings/1560](http://www.ndia.org/meetings/1560) to register online.

### FAX:

Register via fax by completing the Registration Form (PDF) and faxing it to (703) 522-1885. Please do not fax any registrations after May 10, 2011. After this date, please bring your completed registration form with you to the meeting to register on-site or register online.

### MAIL:

Registration forms (PDF) may be mailed to: NDIA, Event #1560, 2111 Wilson Blvd., Suite 400, Arlington, VA 22201. Please do not mail any registrations after May 2, 2011. After this date, please bring your completed registration form with you to the meeting to register on-site or register online.

Registrations will not be taken over the phone and payment must be made at the time of registration.

## CANCELLATIONS:

Cancellations until 05/6/11 receive a refund minus a \$75 cancellation fee. No refunds for cancellations received on or after 05/7/11. Cancellations must be made in writing. Substitutions welcome in lieu of cancellations. Please e-mail your cancellations or substitutions to Mary Katherine Saladino via email: [msaladino@ndia.org](mailto:msaladino@ndia.org)

	EARLY (UNTIL 3/29/11)	REGULAR (3/30/11-5/6/11)	LATE (AFTER 5/6/11)
GOVERNMENT ACADEMIA/ALLIED GOV.	\$450	\$495	\$555
INDUSTRY NDIA MEMBER	\$550	\$605	\$680
INDUSTRY NON-NDIA MEMBER	\$625	\$685	\$775

**55th Annual Fuze Conference**  
The Grand America, Salt Lake City, UT •  
May 24-26, 2011 • Event #1560

National Defense Industrial Association  
2111 Wilson Boulevard, Suite 400  
Arlington, VA 22201-3061  
(703) 522-1820 • (703) 522-1885 fax  
[www.ndia.org](http://www.ndia.org)



- 3 Ways to sign up: 1. Online with a credit card at [www.ndia.org](http://www.ndia.org) ☐ Address change needed  
2. By fax with a credit card — Fax: 703-522-1885  
3. By mail with a check or credit card

NDIA Master ID/Membership # \_\_\_\_\_ Social Security # \_\_\_\_\_  
(if known—hint: on mailing label above your name) (last 4 digits — optional)

Prefix \_\_\_\_\_  
(e.g. RADM, COL, Mr., Ms., Dr., etc.)

Name First \_\_\_\_\_ MI \_\_\_\_\_ Last \_\_\_\_\_

Military Affiliation \_\_\_\_\_  
(e.g. USMC, USA (Ret.) etc.)

Title \_\_\_\_\_

Organization \_\_\_\_\_

Street Address \_\_\_\_\_

Address (Suite, PO Box, Mail Stop, Building, etc.) \_\_\_\_\_

City \_\_\_\_\_ State \_\_\_\_\_ Zip \_\_\_\_\_ Country \_\_\_\_\_

Phone \_\_\_\_\_ ext. \_\_\_\_\_ Fax \_\_\_\_\_

E-Mail \_\_\_\_\_

Signature\* \_\_\_\_\_ Date \_\_\_\_\_

**Preferred way to receive information**

Conference information ☐ address above ☐ Alternate (print address below) ☐ E-mail

Subscriptions ☐ address above ☐ Alternate (print address below)

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# 55th Annual Fuze Conference

**“Fuzing’s  
Evolving  
Role in  
Smart  
Weapons”**

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# Air Armament Center

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*War-Winning Capabilities...On Time, On Cost*



## AF Nonnuclear Munitions Safety Approval Process

An Overview

**U.S. AIR FORCE**

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This presentation is cleared for public release

# **AF Nonnuclear Munitions Safety Approval Process**

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- Who: Melvin Duval, Chief, AAC/SES
- Where: AF System Safety Office, Air Armament Center
- Experience: 20 + years in acquisition at Eglin, Chief Engineer several times, ~6 years in AAC/SES
- What: Overview of what is needed for a successful Nonnuclear Munitions Safety Board (NNMSB) evaluation

# Background

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- System Safety begins at the inception of the program
- Acquisition management authorities need to ensure system safety is an integral part of the acquisition strategy. (AFI 91-202, Chapter 9 and AFI 91-205)
- The AAC System Safety Office (AAC/SES) is primary AF source of conventional munition safety expertise
  - Ensuring program design safety requirements
  - Assisting in defining contractual system safety requirements
  - Supporting the systems engineering processes
  - Evaluating and documenting design as required for NNMSB safety approval/ certification actions for all conventional munition systems



# Background

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- NNMSB Core Mission
  - Review Authority and System Safety Group for All USAF Conventional Munitions
  - Advisor to Acquisition Authorities on Design Safety and Qualification Issues
  - Approval Authority for Airborne Flight Testing of Uncertified, Live-Loaded Munitions and Associated Subsystems
  - Design Safety Certification Authority for all Air Force Conventional Munitions
- AAC/SES, as NNMSB Executive Secretariat, assures execution of the Board's Core Mission

# Background

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- Authority rests with AFI 91-205
- Chairperson: Chief, Weapons Safety Division, Hq AF Safety Center
- Membership:

Air Combat Command	AF Materiel Command
Air Mobility Command	AF Operational T&E Center
AF Special Operations Command	Air Education & Training Cmd
Pacific Air Forces	Air National Guard
USAF Europe	AF Reserve Command
Air Force Space Command	Global Strike Command
- AFI 91-205 also designates AAC/SES, through Hq AFMC, as the agency to provide the Technical Support of the NNMSB

# USAF Nonnuclear Munitions Safety Board

## AAC/SES Role

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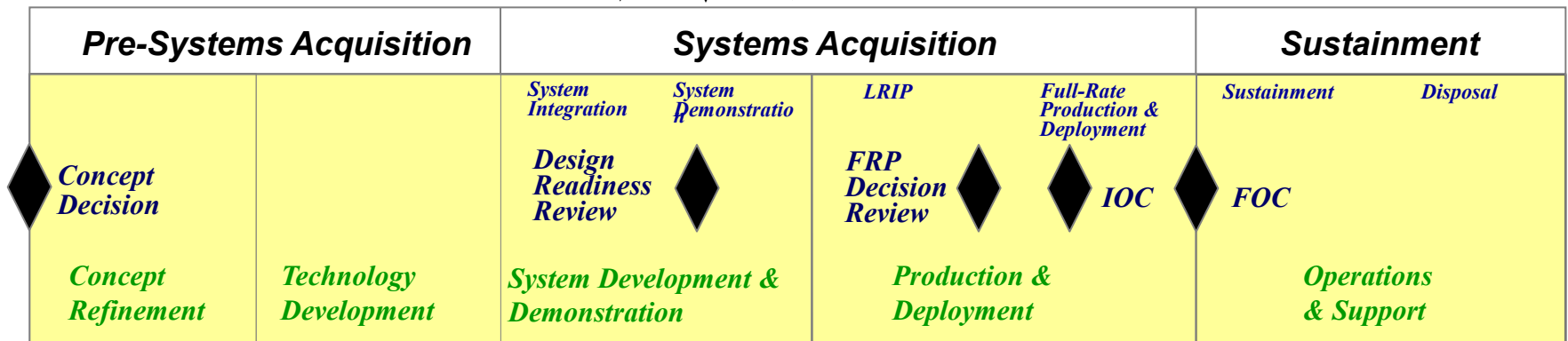
- AAC/SES is the Engineering Arm of the NNMSB
  - Performs Hazard Analyses
  - Performs Independent Fault Tree Analyses
  - Generates Safety Studies for assigned systems
  - Briefs the Safety Studies to the NNMSB
  - Obtains Approval for Live Flight Test/ Recommendation for Certification for Operational Use
- SES is part of the systems engineering team and will work with you from the start of the program through all milestones

# USAF Nonnuclear Munitions Safety Approval Process

*Approval for Live Flight Test*

*Informational Brief*

*Recommendation for Certification for Operational Use*



- Meeting the NNMSB is event driven, not milestone
- NNMSB scheduled Boards are April and October
- Special Boards can be held out of cycle if required
- Funding required for Board members' TDYs

# USAF Nonnuclear Munitions Safety Approval Process

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- First meeting with the Board is informational brief
- Scheduled 6 to 12 months before first live flight test
- Informational brief given by contractor in most cases
- Content is high level with specifics on safety aspects
- Feedback from the board will be comments on design, implementation, handling and storage
- Outcome will be concept agreement, subject to implementation

# USAF Nonnuclear Munitions Safety Approval Process

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- Second meeting with the Board is live flight test
- Live flight test includes live fuze, warhead, rocket motor, live Flight Termination System (FTS) or combination thereof
  - Live FTS has Range Safety and System Safety aspects
- Called Test Hazards Assessment Review (THAR)
  - THAR written by and presented to NNMSB by SES
  - THAR goes to NNMSB 30 days ahead of review
  - SES prep typically 30 days – Data in by 60 days ahead
  - Serial fashion is best – Don't wait for complete package
  - Must be approved by NNMSB for test to proceed

# USAF Nonnuclear Munitions Safety Approval Process

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- Third meeting with the Board is operational use
- Occurs after all testing is complete with no safety related failures – Can be held with minimal work left to conduct
- Documented by Technical Munitions Safety Study (TMSS) and in some cases by Munitions Safety Analysis for non-complex items – Time line is the same as THAR
- TMSS generated by and presented to NNMSB by SES
- Outcome is recommendation for certification for operational use by the NNMSB – May result in action items

# USAF Nonnuclear Munitions Safety Approval Process

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- For joint programs, SES will work with Service System Safety Counterparts to coordinate with and support review milestones, including formal Joint Meetings of the Boards
  - Key Distinction—There is no —Joint Board”
- Service Counterparts are invited to any review they have need to attend
- Can be informational or formal depending on requirements



# USAF Nonnuclear Munitions Safety Approval Process

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- What is important to know about the SES approach?
  - Primary desire is for concrete understanding of all safety critical elements of system, subsystem and components including:
    - Clear and detailed comprehension of design
    - What the hazards are to personnel/ property
    - Who will use the system and how they will use it
- Is an iterative process - —“Come Early, Come Often”
  - The earlier we understand your system, the better we can help you through the process

# USAF Nonnuclear Munitions Safety Approval Process

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- What is important to know about the SES approach? (cont)
- No formal submission guidelines or format requirements
- Emphasis is on technical content, not format
- Technical content is basically the same as for other service Boards and for a well prepared Safety Assessment Report – makes a good data transfer vehicle
  - Well defined/detailed physical/functional description
  - Full schematic diagrams of adequately mature design
  - Well defined/documented safety analyses
  - Well defined/documented safety specific testing
  - Well defined/documented system/subsystem testing

# USAF Nonnuclear Munitions Safety Approval Process

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- What to do to maximize your probability of a successful NNMSB?
  - Provide clear schedule requirements for program
  - Provide adequate information on system
  - Provide information in a timely manner
  - Provide technical support to Fault Tree Analysis
  - Provide support at the NNMSB Meeting
  - Respond to input from SES and the NNMSB
  - Notify AAC/SES of Program Changes ASAP
  - Work issues in real time -- No Surprises!!

# USAF Nonnuclear Munitions Safety Approval Process

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- As said before, our motto is —Come Early, Come Often”
  - Contact assigned engineer and set up informal and formal review times/dates
  - Be prepared to discuss the system at the lowest levels – Typically with the designer
  - Be prepared to discuss all hazards of the system
  - Be aware you are not the only one wanting a review, so plan ahead and have back-up dates ready

# USAF Systems Safety Location



# Questions...

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# **NDIA's 55th Annual Fuze Conference**

## **NAVY OVERVIEW**



**Randall Cope**  
**Associate Department Head for Energetics**  
**NAVAIR China Lake**

# ***Outline***

- Navy Fuze S&T Strategy
- Navy Fuzing Future Directions
- Navy Fuze Work Highlights
- Summary

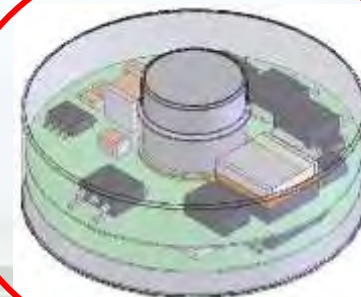
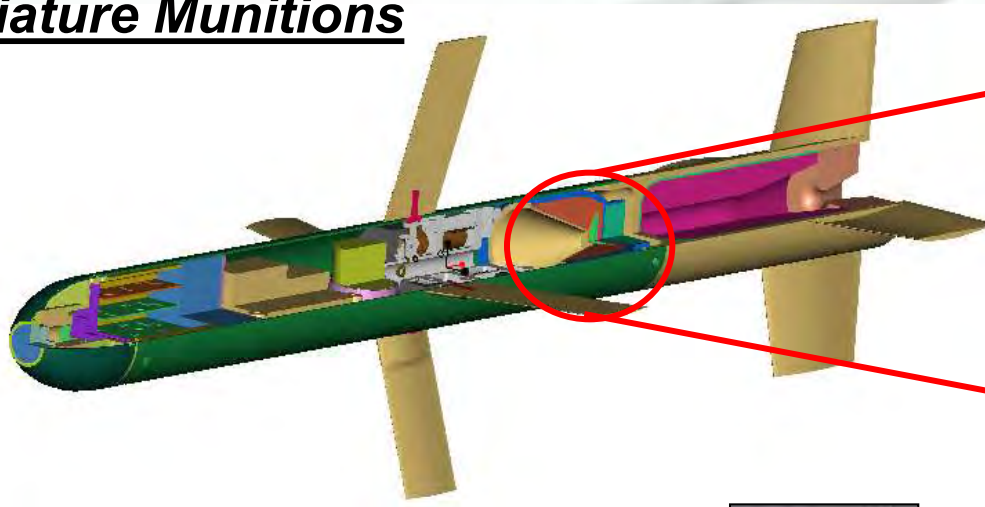


# ***Navy S&T Strategy***

- **Less of a formal Strategy, but more of a fuzing path into the future**
  - **Smaller - We really see that fuzing is heading in the direction of smaller is better.**
    - **Weapons are getting smaller and smaller sizes allow for redundancy to help reliability.**
  - **Reliability - Higher reliability is also a big player for Navy fuzing. Sub-munitions have very high reliability expectations and more traditional fuzing is also wanting higher reliability.**
  - **Lower Cost - With budgets falling, the pressure is on to make all weapons and weapons systems cost less.**

# Navy Future Directions

## Miniature Munitions



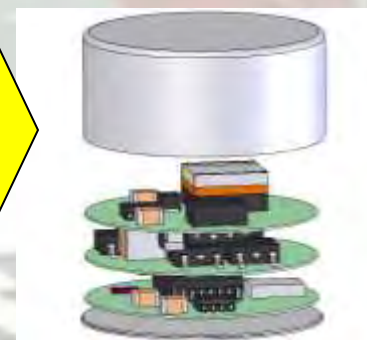
**State-of-the-Art  
In-Line & Out-of-Line  
Safe-Arm Devices**



**Large and bulky  
Electro- Mechanical  
Safe-Arm Devices**



**Complex Electro- Mechanical  
Safe-Arm Devices**



**Advanced MEMS and  
Electronic Technologies**

# ***How Will We Get There?***

- **Smaller and more reliable and robust electronics and power conditioning technologies.**
  - **Improved reliability across all fuze applications.**
- **Improved detonator/initiator designs and components.**
  - **Improved IM and variable output weapons characteristics.**
- **Improved MEMS Technologies and producible MEMS designs.**
  - **Smaller and more robust fuzing application.**
  - **New families of contact sensors and fuzing devices**
- **Leverage spiral development of existing fuzes.**
  - **Improved reliability and capability.**
  - **Stop-gap to help support fuzing industry.**
  - **Demonstration beds for new technologies.**
- **Service life extension programs for existing fuze inventories.**



# Navy Tech Money Sources

ONR

JFTP

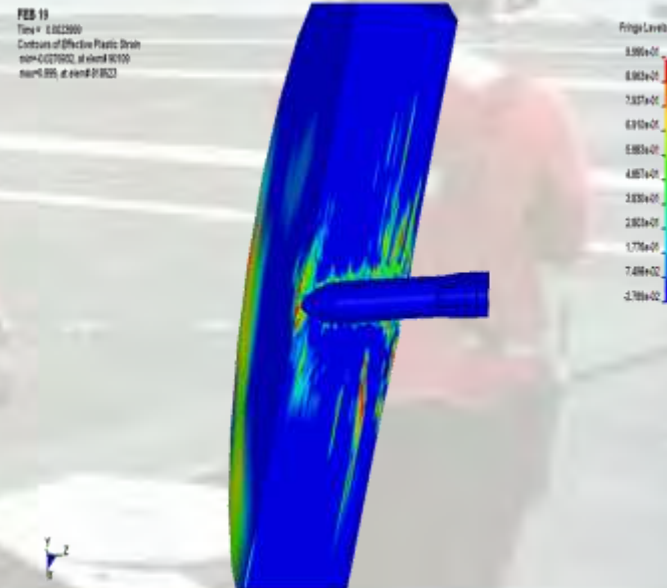
Direct Technology  
Programs

# Navy Tech Money Sources



# ***Dynamic Impact Simulation of Deceleration Pulse for Void Sensing Fuzes***

- Evaluation of latest LS-DYNA Impact Simulation Software
- Creating LS-DYNA input templates for hard target penetration application
- Impact deceleration, stress & strain calculated for penetrator Fuzes
- Results compared to NAVAIR cannon and sled test data

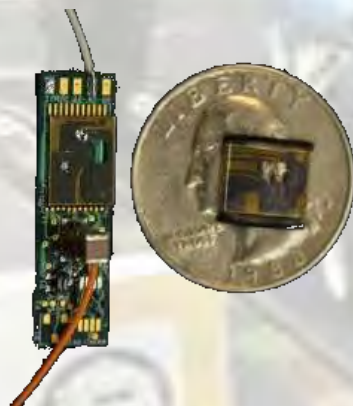
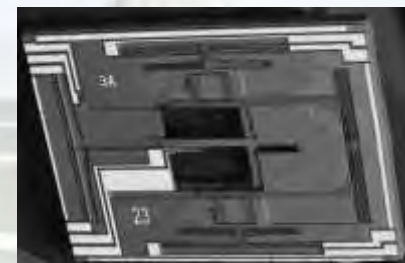


Open Session IVB Briefing provided by Dr. Paul Glance

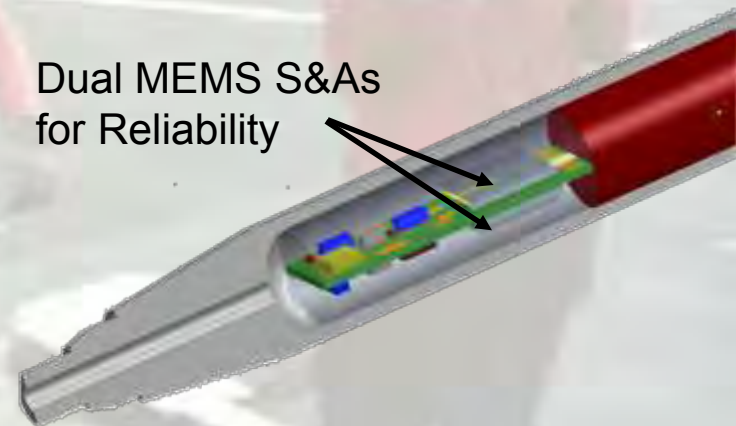


# ***MEMS Fuzing for High Reliability Systems***

- Development of G-hardened miniature Fuze component technology mine defeat penetrator application
  - Silicon on Insulator (SOI) MEMS S&A
  - Micro detonator
  - MEMS initiator
  - Low-cost miniature fire-set



Dual MEMS S&As  
for Reliability

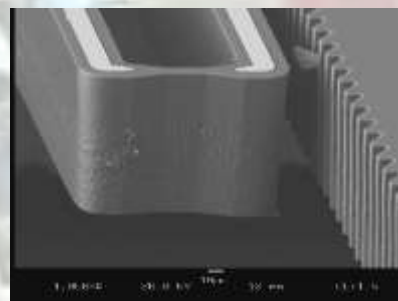


# ***A Versatile Explosive Train Integrated into a MEMS S&A Device***

- Development of integrated initiation and explosive train component technology for MEMS based S&A application
- Developed for small volume applications turning tight corners
- Employs CI-20 based explosives RSI-007 & EDF-11 ink



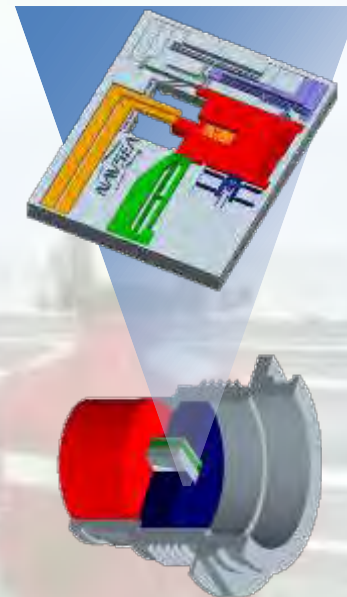
**Vaporization of an  
IHDIV MEMS initiator**





# ***Navy MEMS Fuze For Marine Corp Flight Control Mortar***

- S&A for 81 mm Precision Urban Mortar Attack (**PUMA**) – Future Naval Capability (FNC)
  - Joint Navy / Army S&T system development
  - Supports Marine Corps Conventional Weapons (CW) Science & Technology Objectives
  - System demonstration in FY14
- MEMS based S&A



# MEMS Retard & Impact Sensors

- **Objective:** Obtain DoD retard and impact sensors with **precision, reliability, producibility and cost effectiveness** by exploiting existing MEMS microfabrication and packaging technologies
- **Traditional coil-spring-mass technology:**
  - Wide performance variability per mechanical spring tolerances
  - Difficult to precisely sense low G's with "macro world" springs
- **MEMS technology appears well-suited for making improved low-G sensors per DoD exploratory work to date:**
  - NAWCWD: precision-electroplated G-sensors
  - NSWCIH: silicon G-sensors and packaging
  - ARDEC: metal G-sensors and packaging
- **FY11 Focus: low-G impact sensors (<100G) & very low-G retard sensors (<5G)**



Illustration and Photograph Courtesy of NAWCWD

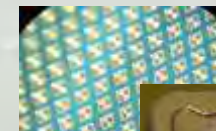


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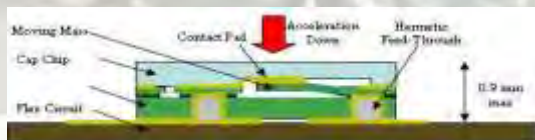
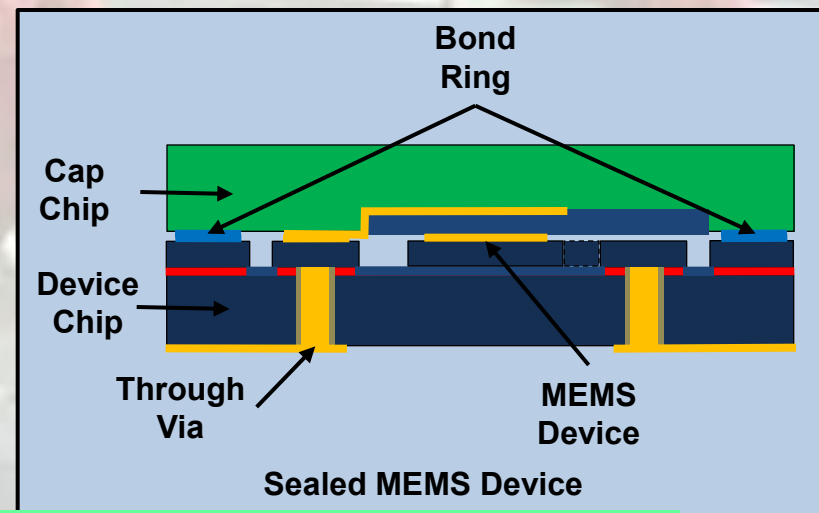
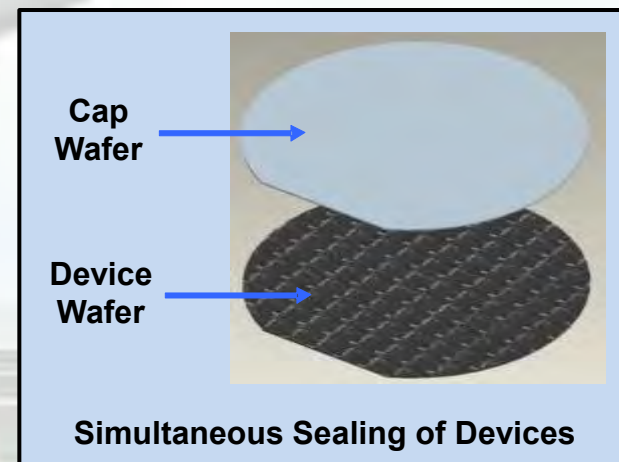


Illustration and Photograph Courtesy of NSWC

Closed Session VB Briefing provided by Mr. Walt Maurer

# Wafer Level Packaging for High Aspect Ratio MEMS

- Develop wafer level packaging techniques that are applicable to high-aspect ratio MEMS devices
  - Wafer bonding
  - Through vias
- Improved reliability and safety of MEMS components in the fuze, including sensors and / or the MEMS S&A chip
- Increased throughput (2 orders of magnitude) and yield of the MEMS manufacturing process
- Lower cost components (submunition applications)

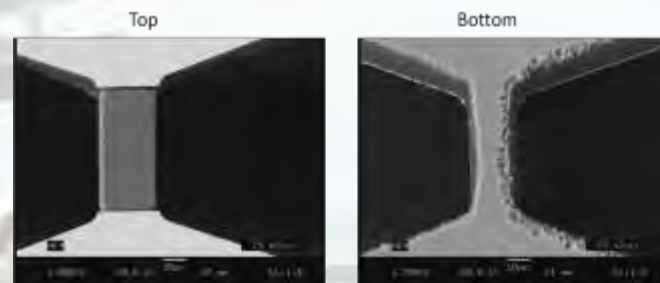


Open Session VA Briefing provided by Mr. Kevin Cochran



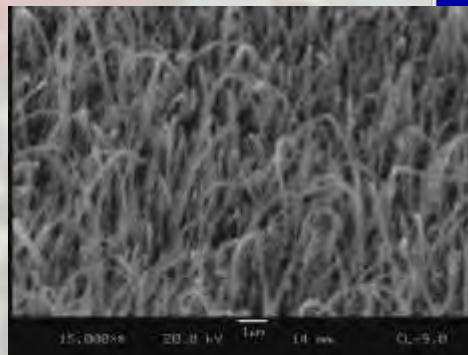
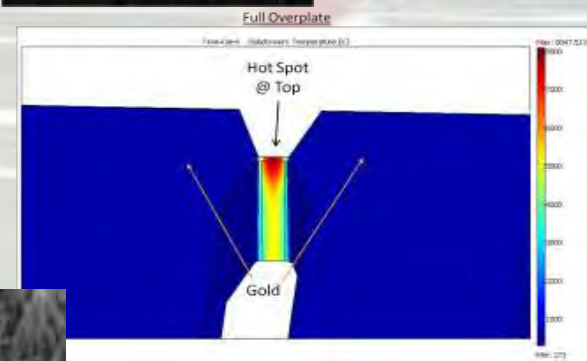
# Enhanced Performance of MEMS Electric Initiators

- Increase the output of an initiator that can be easily integrated into a MEMS fuze to maximize micro-detonator output
  - Replaces low performance energetic
  - Prompt initiation ( $< 2\mu\text{s}$ )
  - Low power ( $< 1\text{mJ}$ )
  - Highly uniform fabrication
- Understand differences between reactive material bridge as compared to simple metal/silicon
- Provides compact, safe and low energy S&A for distributed multipoint initiation systems.



DRIE of Si Bridge

Model Hot Spots

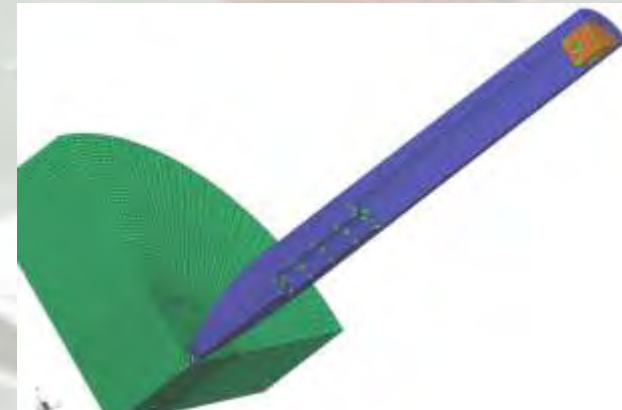
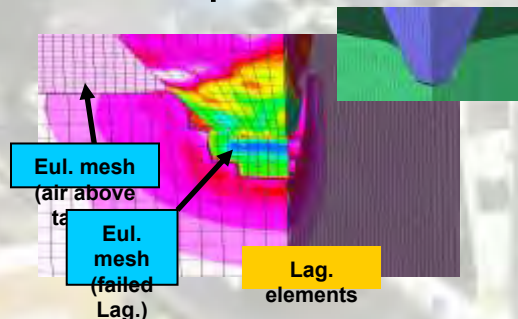


RM Nanowires

Open Session VA Briefing provided by Mr. Daniel Pines

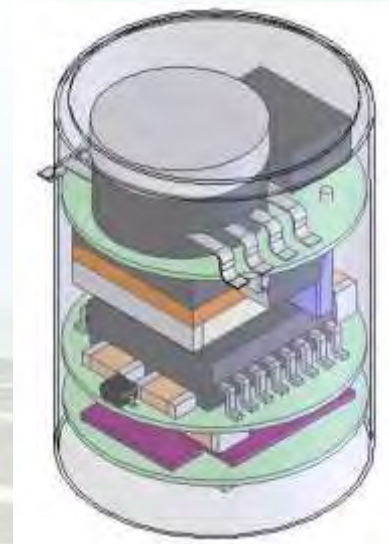
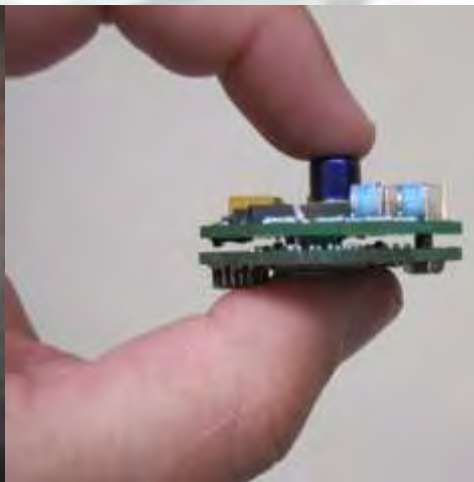
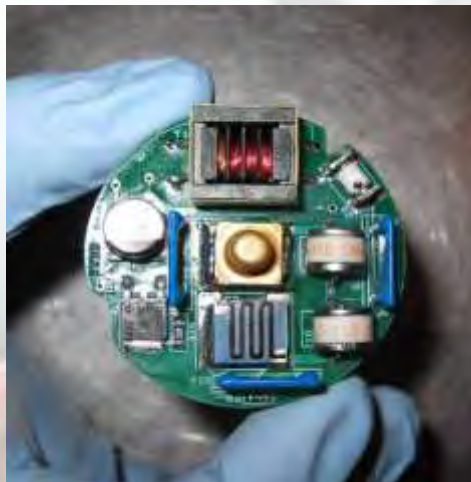
# Improving Fuze Environment Prediction During Hard Target Penetration Using A Coupled-Code Erosion Technique

- Development of Element Deletion – Material Donation (EDMD) Erosion technique to improve prediction of forces experienced by fuzing components during hard target penetration
  - Replace artificial void with real target material
  - Reduce “numeric” noisy in fuze region
  - Prevent tensile failure of elements next to failed element
  - Avoid small time steps that stop the calculation
  - Overall improvement of HT Fuzing M & S

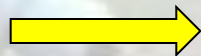


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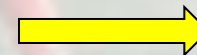
# Low-Cost Miniature Electronic Safe-Arm Device (ESAD)



2.0 in<sup>3</sup>\*  
(Demonstrated)



1.1 in<sup>3</sup>



0.44 in<sup>3</sup>  
(Near Future)

- All COTS components
- Production Low Energy Exploding Foil Initiator (LEEFI)
- Fuze safety board recommended 3-interrupter architecture
- Very low cost high-voltage switch
- Parts cost for this architecture ~ \$260 (1000 unit pricing)

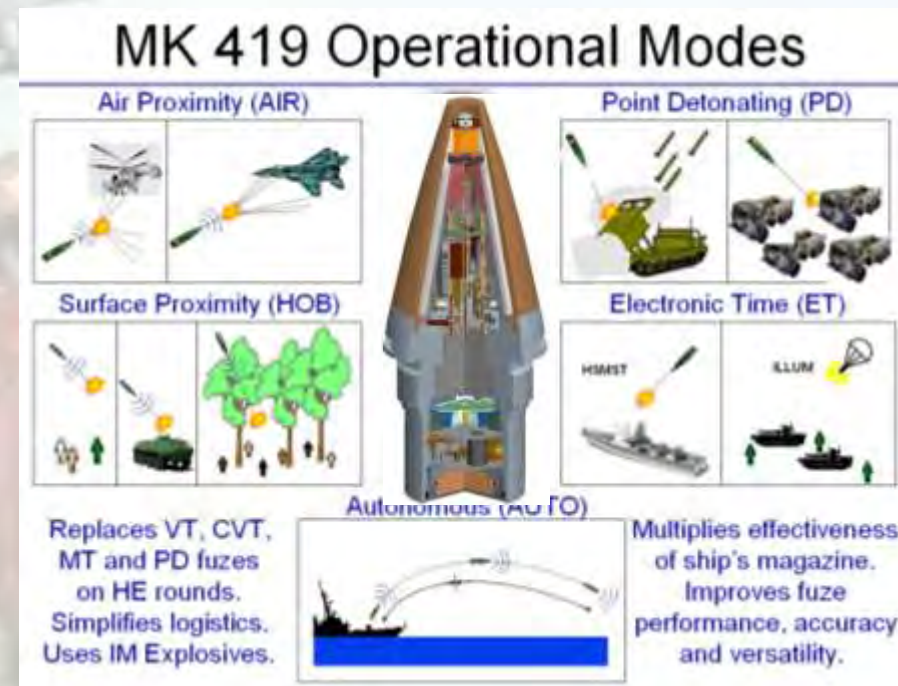
**\*has now had 4 successful flight tests where the ESAD functioned flawlessly**

Open Session VA Briefing provided by Mr. Michael Haddon



# MK419 Mod 1 Multi-Function Fuze Product Improvement Program

- The MK 419 Mod 1 Multi-Function Fuze fits 76 mm and 5 inch AURs.
- The PIP goal was to reduce cost.
- Major cost drivers:
  - Cheaper electronic components.
  - Smaller footprint of electronic devices.
  - Configuration modification for efficient manufacturing.
  - Sophisticated assembly techniques to reduce cycle time.



Open Session IVA Briefing provided by Mr. Richard Chapman

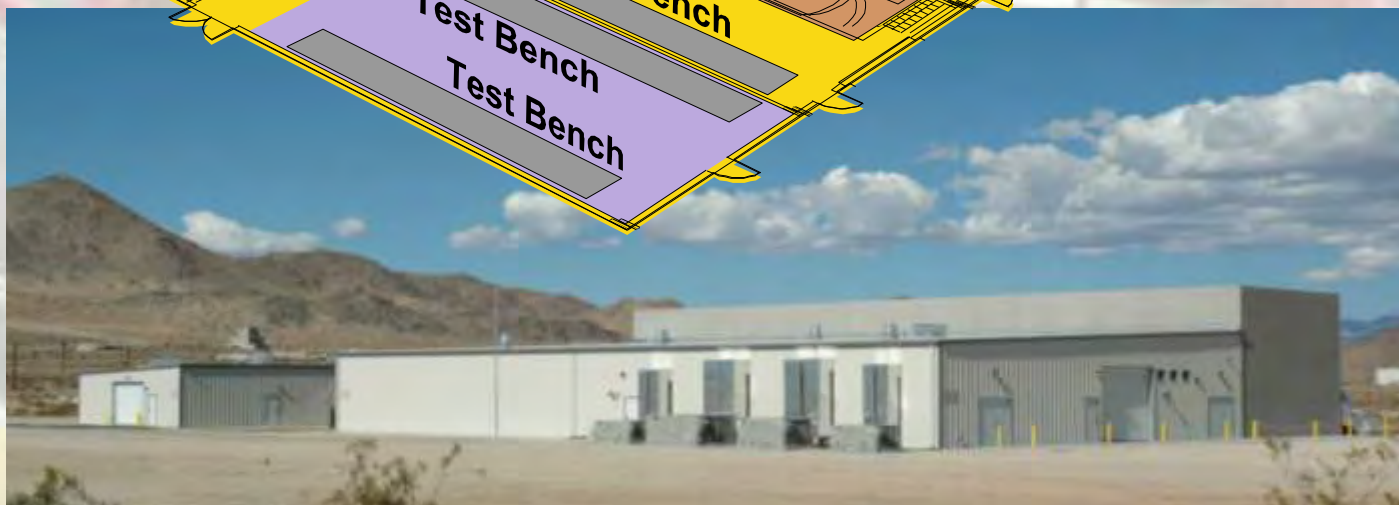
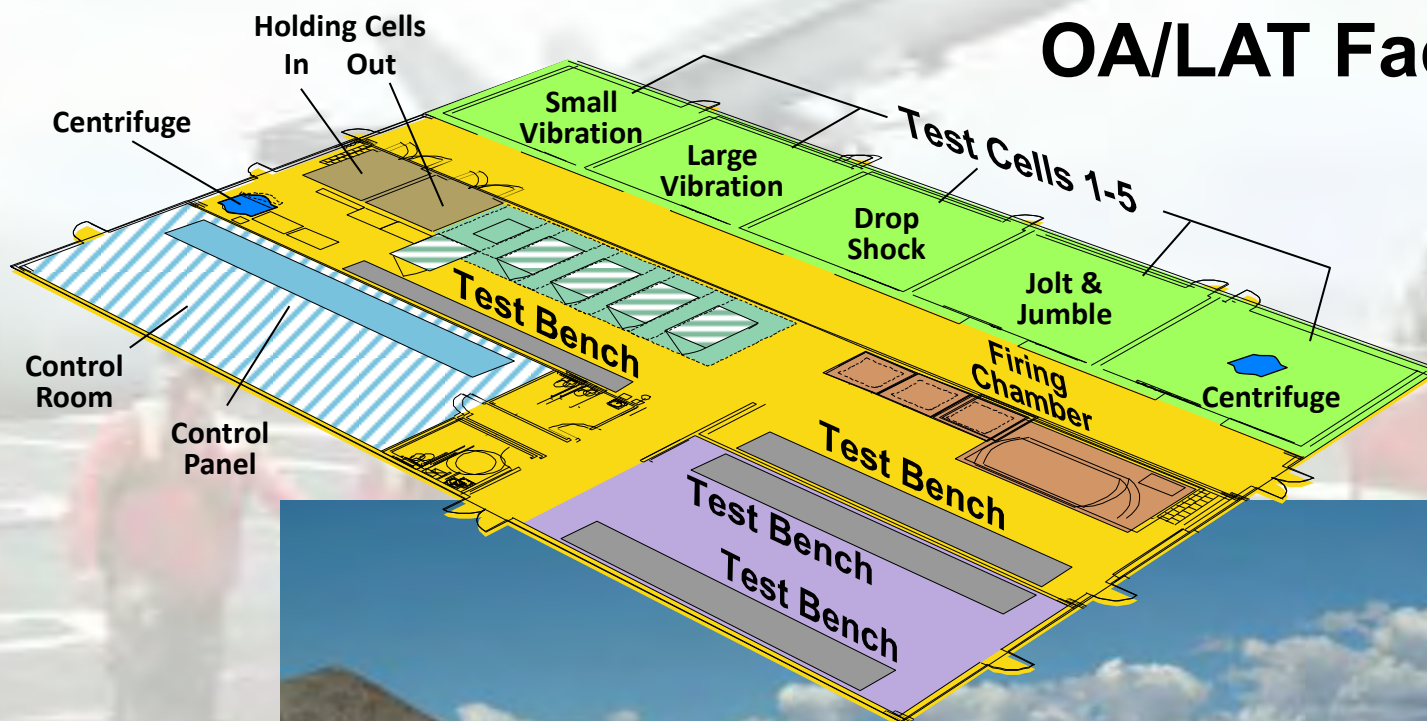
# ***Near-Term Trends for Navy Fuzing***

- **Potential cost effective approaches for fuzes.**
  - **Leverage spiral development of existing fuzes.**
  - **Refurbish existing inventories.**
  - **Modify existing inventories to meet new requirements.**
  - **Demonstration beds for new technologies.**
- **Service life extension programs for existing fuze inventories.**
  - **Increase Ordnance Assessment (OA) Activities**
  - **Establish Ordnance Health Assessment program**
- **New State-of-the- Art Fuze Assessment Test Facilities**
  - **Modern multi-fuze test sets and data acquisition**



# New Navy Fuze Capabilities

## OA/LAT Facility



# *Summary*

Smaller, More Robust, Higher Reliability and Lower Cost fuze designs are future thrusts for future Navy Fuzing



# **Joint Fuze Technology Program (JFTP) 55<sup>th</sup> Annual NDIA Fuze Conference**

**25 May 2011**

## **Joint Fuze Technology Panel**

**Charles Kelly (OUSD AT&L PSA LW&M)**

**Lawrence Fan (Navy)**

**Timothy Tobik (Air Force)**

**Philip Gorman (Army)**

## **Lawrence Fan (Presenter)**

**Indian Head Division, Naval Surface**

**Warfare Center**

**(301) 744-6157**

**lawrence.fan@navy.mil**



# JFTP Overview

- JFTP is a 6.2/6.3 national program established (FY10 start) to develop and mature technologies for improving future fuzing performance, survivability, and reliability
- JFTP governance and processes are modeled after the Joint Munitions Program (JMP) and the Joint Insensitive Munitions Technology Program (JIMTP)
  - Managers from Services and DTRA
- JFTP leverages and coordinates with projects in JMP, JIMTP and Service S&T
- Projects are selected based on evaluation of proposals from Gov't, Industry and Academia

# Joint Fuze Technology Program Management Structure



**OUSD(AT&L)/  
PSA/LW&M**

**Technical Advisory  
Committee**



**JOINT FUZE TECH PANEL OVERSIGHT COMMITTEE**

**PROGRAM MANAGERS**

Charles Kelly, Lawrence Fan, Phil Gorman, Tim Tobik

## FUZE AREA TECHNOLOGY GROUPS

### **FATGI – Hard Target / Survivable Fuzing**

Chair  
Danny Hayles (DTRA)

Co-Chairs  
John Kandell (Navy)  
Bill Konick (Army)  
Howard White (AF)

SME Participants

### **FATGII – Tailorable Effects & Initiation**

Chair  
Gene Henderson (Army)

Co-Chairs  
Daniel Lanterman (Navy)  
George Jolly (AF)

SME Participants

### **FATGIII – High Reliability Fuzing**

Chair  
John Hendershot (Navy)

Co-Chairs  
Steve Smith (AF)  
Tom Crowley (Army)

SME Participants

### **FATGIV – Enabling Fuze Technologies**

Chair  
Chris Janow (Army)

Co-Chairs  
Matt Bridge (AF)  
Bruce Hornberger (Navy)

SME Participants



# Fuze Area Technology Groups

## FATG I – Hard Target / Survivable Fuzing

- 1.1 Improved M&S
- 1.2 Fuze Environment
- 1.3 Next Generation Fuzing Hardware

## FATG II – Tailorable Effects

- 2.1 Initiation & Multi-point
- 2.2 ESAD Based Multi-point Initiators
- 2.3 MEMS Based Multi-point Initiators
- 2.4 Smart Fuzing: Algorithms, timing and control
- 2.5 Adv Fuze Initiation

## FATG III – High Reliability Fuzing

- 3.1 Fuzing Architecture
- 3.2 Fuzing Components
- 3.3 UXO reduction features

## FATG IV – Enabling Fuze Technologies

- 4.1 Common / Modular Fuze Architecture
- 4.2 Components Technologies
- 4.3 Proximity Sensors
- 4.4 Weapons Effects & Damage Assessment
- 4.5 Fuzing Power Sources





# Funding

	FY 10	FY 11	FY 12 PBR	FY 13	FY 14	FY 15	FY16
JFTP 6.2	3.849	7.833 (requested) 5.400 (actual total)	7.167	5.656	6.604	7.312	7.520
JFTP 6.3	0	3.577 (requested) 1.077 (actual total)	4.889	6.098	6.835	8.350	8.606







# FY12 JFTP Summary

- Funding levels from FY12 submitted budget:
  - 6.2 - \$7.167M total
  - 6.3 - \$4.889M total
- Selection ongoing for FY12 new starts
  - Proposers receive final go/no-go when FY12 budget is released ~ Nov 12
- Industry involvement:
  - Conveyed FATG goals and higher priority goals via DOTC Fuze call for proposals
  - Additional details at DOTC General Membership meeting – July 11
- Program Plans (GOTChA charts) to link weapon requirements and needs to fuzing technologies to JFTP projects and gaps



# Next Call for WP/Proposals

## Call for White Papers

- FY13 cycle starts in Dec 11/Jan 12
- Call is distributed to DoD, DOE and TAC members and to NWECC/DOTC
- FATG goals and needs conveyed
  - Focus on specific gaps not currently addressed
- 6.2 and 6.3 projects solicited (3 pages)

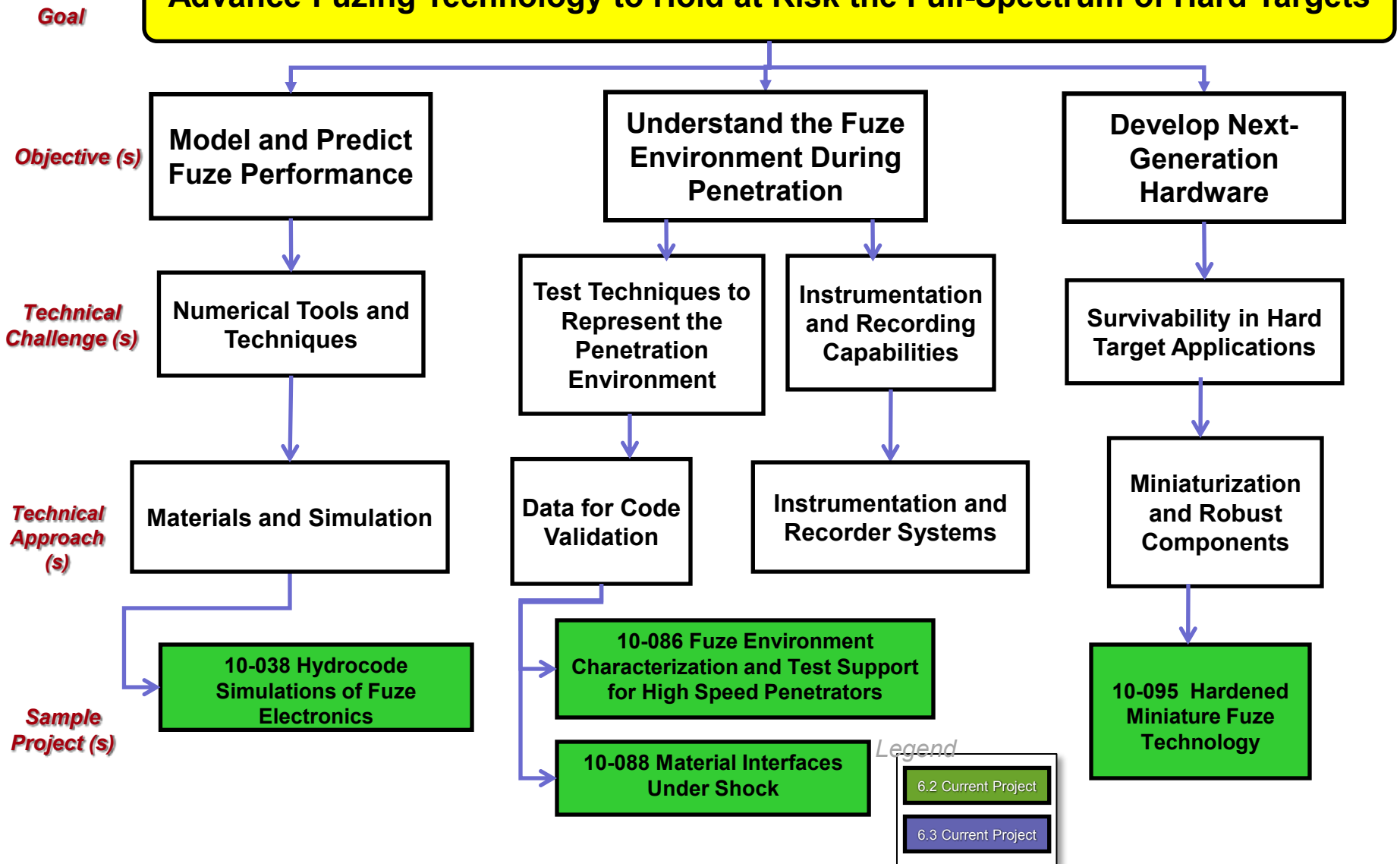
## White Paper Content

- What FATG goals are being addressed
- Description of technology
- Statement of technology maturity
- Transitions (for 6.3 identify offices expected to provide endorsements and leveraging/cost sharing)
- Deliverables (what/when) and their relevance
- Yearly ROM costs and schedule





# FATG / Hard Target Fuzing GOTChA

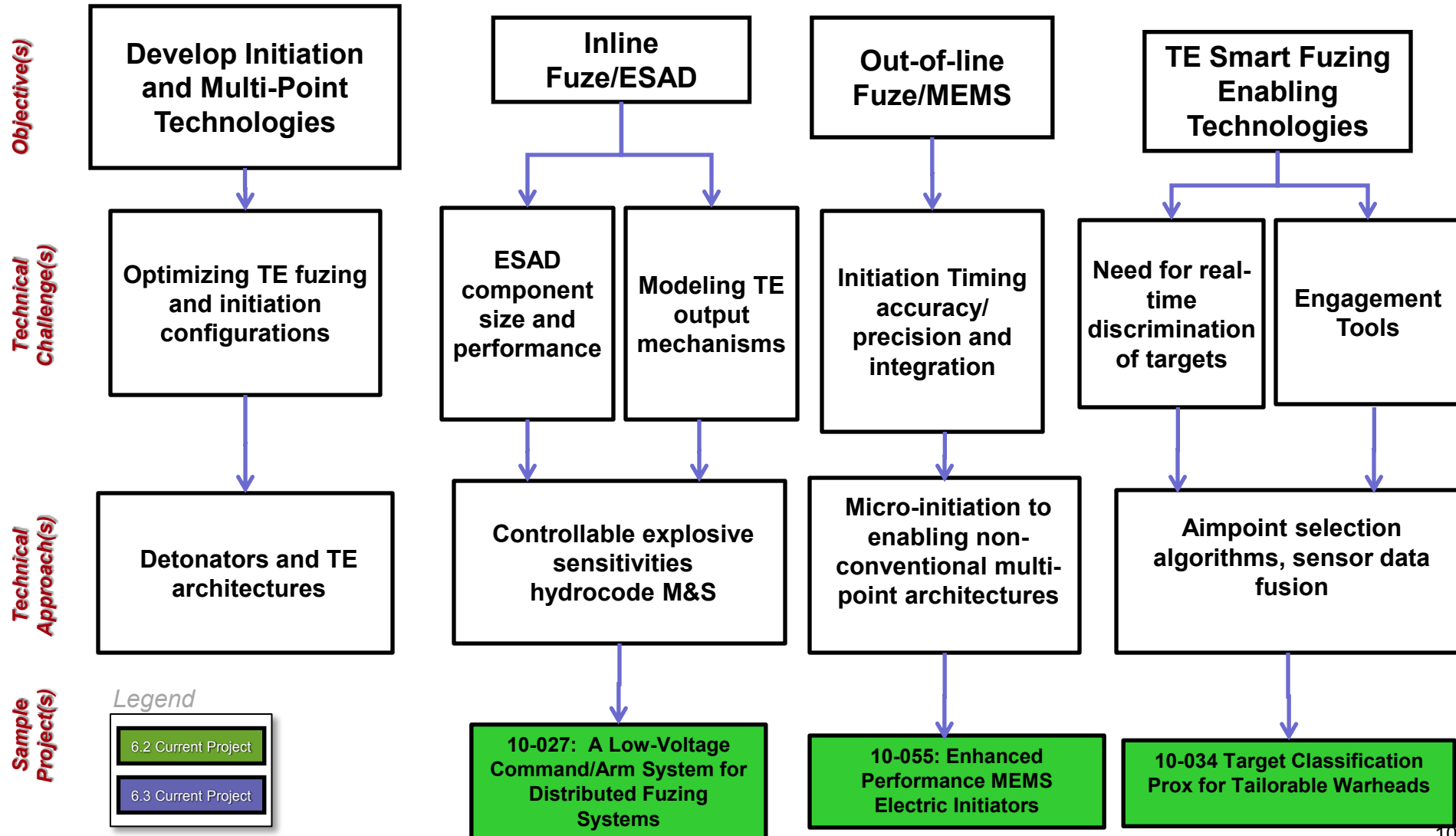




# FATG II Tailorable Effect Fuzing GOTChA

Goal

**TAILORABLE EFFECTS (TE) WEAPON SYSTEMS TECHNOLOGIES THAT ENABLE  
SELECTABLE YIELD OPTIONS APPLICABLE to MUNITIONS SYSTEMS**





# FATG II Tailorable Effect Fuzing GOTChA

**ADVANCE FUZE INITIATION TECHNOLOGIES for BROAD WEAPON APPLICATION**

Goal

Legend

6.2 Current Project

6.3 Current Project

Improve Weapon  
System Fuze  
Train  
Performance  $O_4$

Overcome existing fireset  
limitations (volume, weight,  
cost).

Initiation of IM materials  
(main warhead, booster  
fills).

Develop improved/advanced  
fireset components.

Develop improved/advanced  
booster components.

Develop improved/advanced  
detonators and initiators.

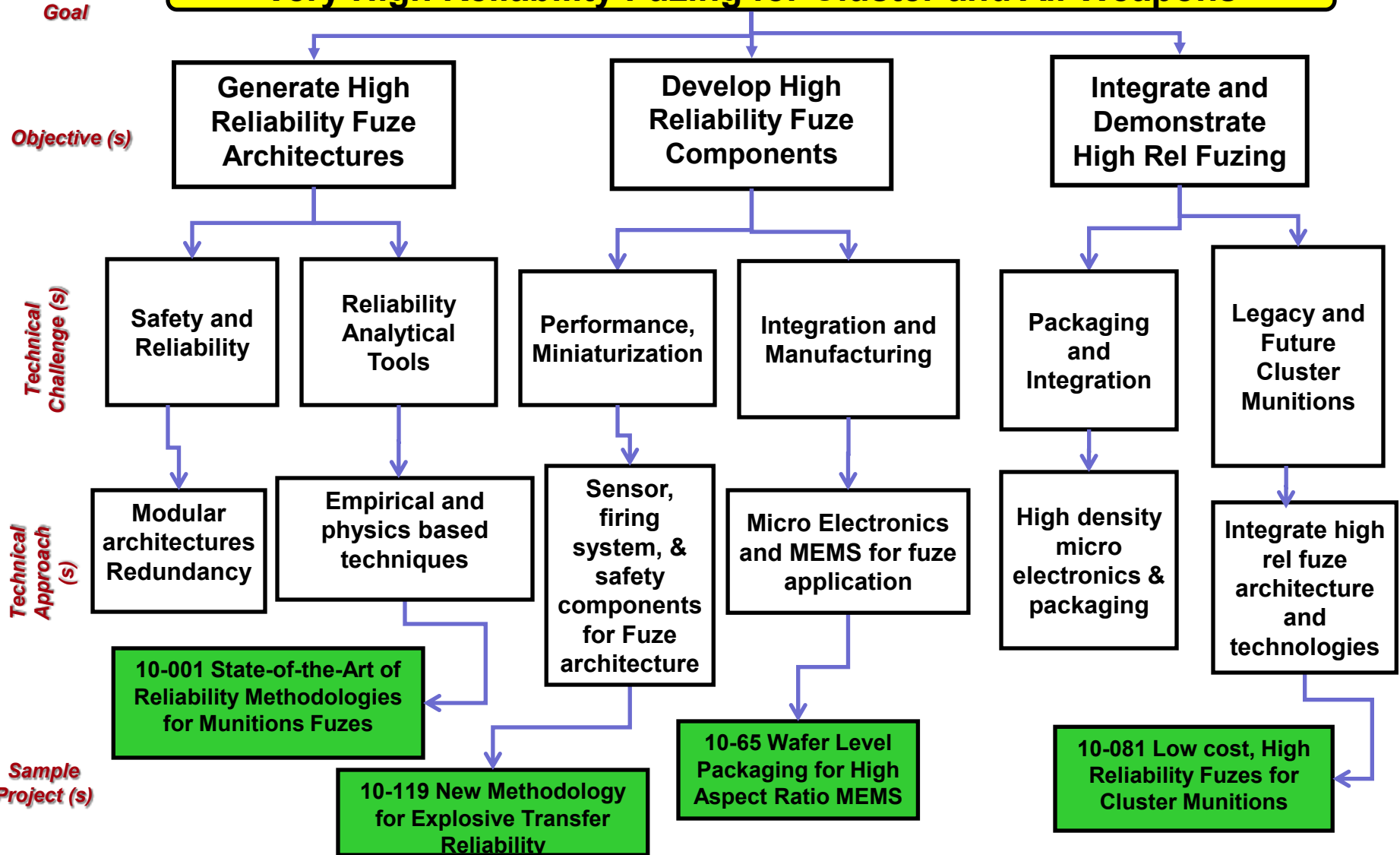
10-102: Integrated Switch  
Slapper

11-I-022: Maturation of a  
Smaller, Cheaper High  
Performance Monolithic  
Ceramic Flyback Transformer  
for High Reliability Firesets

11-G-015: PGK Explosive  
Train Redesign for IMX-101  
Compatibility

# FATG III High Reliability GOTChA

## Very High Reliability Fuzing for Cluster and All Weapons





# FATG IV Enabling Fuze Tech GOTChA

Goal

## FATG IV Fuze Sensors and Power Sources

Objective (s)

Develop Miniaturized, Robust and Affordable Fuzing Sensors

Improved Fuzing Power Source Performance for a diverse range of applications  
Increased Output (Power & Energy Density Improvements for higher power needs)

Technical Challenge (s)

Performance and technology development of proximity sensors, environmental safety sensors and retard / impact sensors

Rise time improvements and Energy density  
Decrease time to set fuze

Technical Approach (s)

Investigate RF, IR and optical sensors  
Develop advanced antennae, transceiver, and signal processing algorithms

Apply advancements in power and materials technologies in compact form factors  
Develop Thermal Battery Materials  
Develop Electrolytes

Legend

- 6.2 Current Project
- 6.3 Current Project

Sample Project (s)

10-042 Next Generation Proximity Sensors

10-010: 6.3 MEMS Retard & Impact Sensor

10-070: Nanofoil-Heated Thin-Film/ Conformal Thermal Battery Construction

10-078: High Energy Density Super Capacitors



# JFTP Calendar

<b>10 Dec 10</b>	<b>Call for FY12 White papers (Gov't and DOTC)</b>
<b>18 March 11</b>	<b>Gov't and DOTC WP Feedback sent and Call for proposals</b>
<b>26-28 Apr 11</b>	<b>Spring JFTP Meeting (Booz Allen Hamilton – Arlington, VA)</b>
<b>15 Jun 11</b>	<b>FY12 JFTP NVEC and Gov't proposals due</b>
<b>13-14 July 11</b>	<b>DOTC General Membership Meeting</b>
<b>23-26 Aug 11</b>	<b>TAC review of JFTP program</b>
<b>Oct/Nov 11 (est)</b>	<b>FY12 JFTP Budget Determined</b>
<b>Nov 11 (est)</b>	<b>FY12 JFTP Project Selection Decision</b>
<b>Dec 11</b>	<b>Call for FY13 White Papers</b>





# 55<sup>th</sup> Annual Fuze Conference

## JFTP Project Briefs

- Session IIIB: High Reliability Fuzing Architecture for Cluster Munitions, David Gudjohnsen, US Army, ARDEC
- Session IVB: The Fuze Environment of Boosted Penetrators Dr. Jason Foley, US Air Force, AFRL Munitions Directorate
- Session IVB: Hardened Miniature Fuze Technology Progress Jefferson Oliver, US Air Force, AFRL Munitions Directorate
- Session IVB: Improving Fuze Environment Prediction During Hard Target Penetration Using A Coupled-Code Erosion Technique, Reid McKeown, US Navy, NSWC Indian Head Division
- Session VA: Wafer Level Packaging for High Aspect Ratio MEMS Kevin Cochran, US Navy, NSWC Indian Head Division
- Session VA: A Low Voltage Command-Arm System for Distributed Fuzing Mark Etheridge, US Army, AMRDEC
- Session VB: MEMS Retard and Impact Sensors, Walter Maurer, Naval Air Warfare Center Weapons Division



# Questions?



# **An Overview Of The U.S. Army Fuze Safety Review Board (AFSRB)**

**55<sup>th</sup> NDIA Fuze Conference  
Salt Lake City, UT**

**Presented By:**

**Chris Janow**

**Chief**

**US Army Fuze Management Office (AFMO)**

**973-724-5438**

**[chris.janow@us.army.mil](mailto:chris.janow@us.army.mil)**

**TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

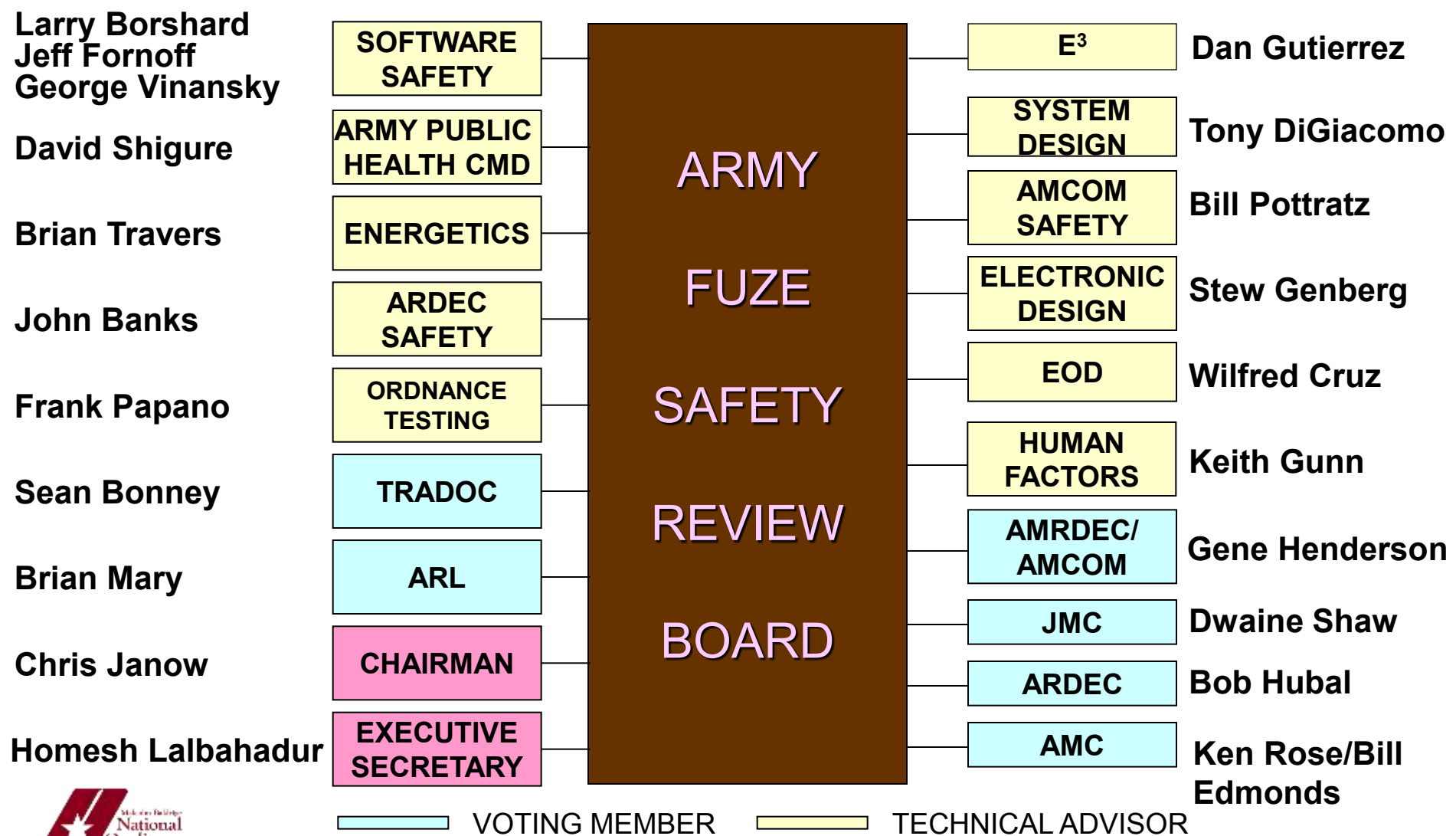
- **Chairman of AFSRB was requested to brief conference on how to get a program through the AFSRB successfully.**
- **Answer.....**

- **Design and test the fuze properly!!!!**

- **AFSRB Overview**
- **Generic Guidelines**
- **ESA Guidelines**
- **Command – Arm Fuzing**
- **Origin of the 500 Volt Requirement**
- **MIL-STD-1316F and STANAG 4187 Edition 4**
- **New ARSRB Guidelines**



- Charged with reviewing fuzing systems and hand emplaced munitions to assure acceptable safety exists and residual risks are properly described in system safety risk documents.
- In existence since late 1960s -
- Authority:
  - AR 385-10, Army Safety Program
  - AR 700-142, Type Classification, Materiel Release, Fielding & Transfer
  - Chartered by CG, Army Materiel Command (1995)
  - AFMO responsibility to operate in charter and AR 70-1, Army Acquisition Policy



- **Performs a safety review of fuze designs by an independent panel of experts**
  - Appraises level of safety inherent in the design
  - Ensures acceptable level of safety is present in final design
- **Presents findings and recommendations to PM**
- **Issues Safety Certifications**
  - Initial Safety Certification issued at request of test agency or project team (non mandatory)
  - Interim Safety Certification issued prior to Type Classification to allow beginning of initial production (mandatory)
  - Final Safety Certification issued prior to Materiel Release to allow fielding (mandatory)

- **Safety Certifications**
  - **Only apply for the specific fuze configuration under review and for that specific application**
  - Some contractor and DOD personnel guilty of implying to potential customers that a previously certified fuze design will “automatically” receive certification in a different application.
  - **NOT NECESSARILY TRUE!!!!**
  - There is no guarantee that a previously approved design will be acceptable for a new or different application.

## What Items Are Reviewed?

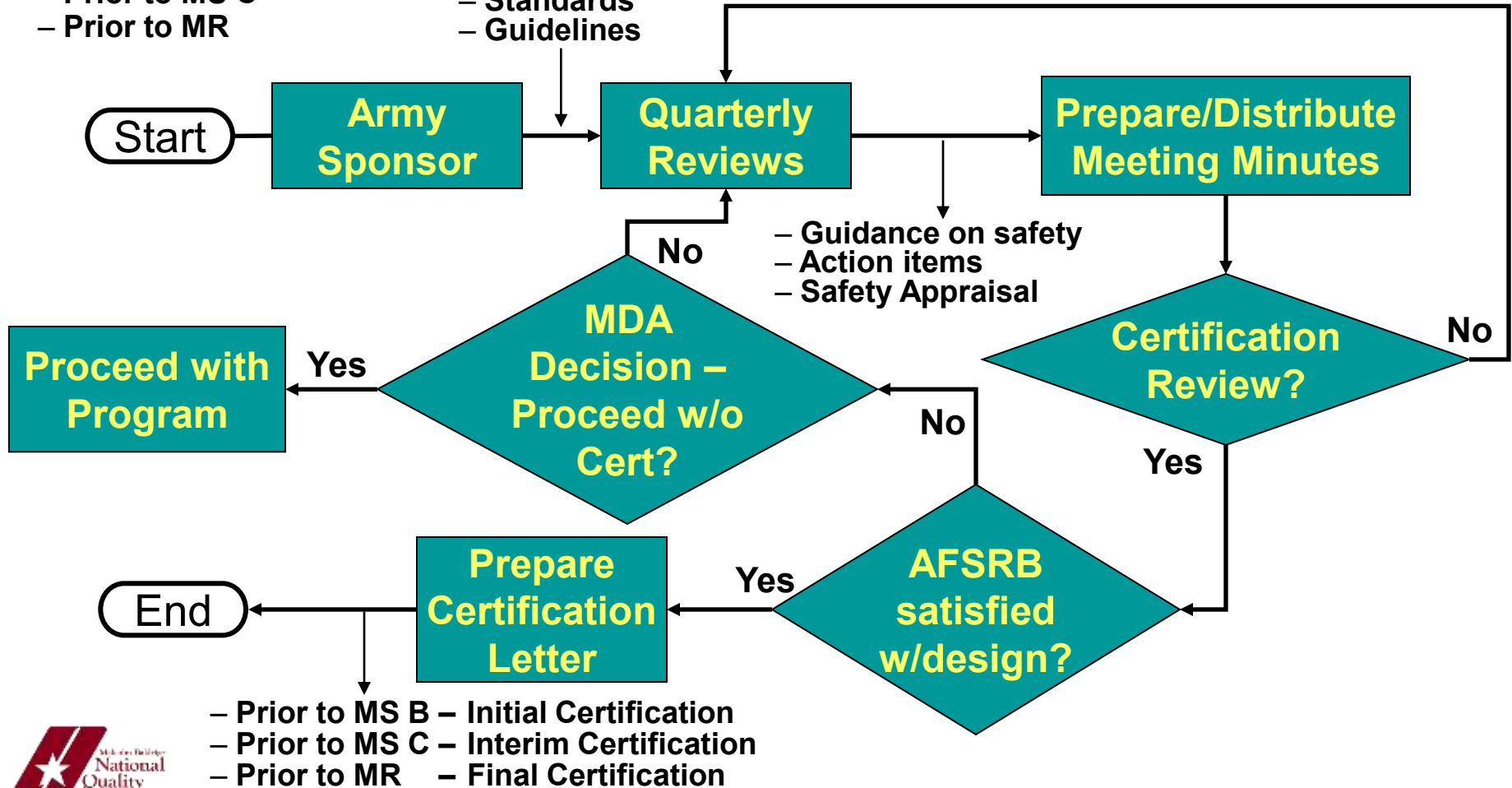
- Any **new fuzing** system design or fuze **procured** by the Army
- Any **modification** (product improvements or materiel changes) of existing fuzing system designs that affect the fuze safety system or a safety critical item
- A **new application** of an existing fuzing system
- Fuzes adapted for Army use from **other** U.S. Military Services
- **Foreign** fuzes for U.S. Army applications
- Fuzes for **Non-Lethal** Weapons as deemed necessary by the appropriate Safety Office (based on hazard/risk)
- All **hand-emplaced ordnance** as deemed necessary by the Chairman of the AFSRB

- **STANAG 4187, Edition 4, Fuzing Systems - Safety Design Requirements**
  - **Mil-Std-1316F, Fuze Design, Safety Criteria For**
- **STANAG 4497, Hand-Emplaced Munitions (HEM), Principles for Safe Design**
  - **Mil-Std-1911A, Hand-Emplaced Ordnance Design, Safety Criteria For**
- **STANAG 4157, Edition 2, & AOP-20, Tests for the Safety Qualification of Fuzing Systems**
  - **Mil-Std-331C, Fuze and Fuze Components, Environmental and Performance Tests For**
- **Experience**



- Read ahead
- Briefing
- Experience
- Standards
- Guidelines

- Prior to MS B
- Prior to MS C
- Prior to MR



- Tests that simulate anticipated manufacturing, logistic and tactical usage environments
- Tests that exceed anticipated storage, transport and operational Fuze level tests
- System and component level tests
- Test types depend upon the fuze/ammunition/weapon
  - Some system level tests can substitute for some fuze level tests
- **HAPPY 60<sup>th</sup> BIRTHDAY TO MIL-STD-331!!! First issued in 1951**

## AOP-20/MIL-STD-331 Fuze Level Tests

### Environmental

- Jolt
- Jumble
- 1.5m Drop
- Salt Fog
- Temp/Humidity
- Extreme Temp Storage
- Thermal Shock
- Trans Vib & Secured Cargo
- E<sup>3</sup>

### Design

- Out of Line Safety
- Minimum Arming
- Explosive Component Safety

- Sequential testing is required by STANAG 4157, to demonstrate robustness against expected and typical life-cycle environments
- New FESWG Fuze Qualification Guideline specifies tests and quantities

# GENERIC GUIDELINES

- **Limit use of safety critical software**
  - Raw data from guidance sensors (i. e., accelerometers) should be passed along to fuze logic devices for processing. This can be sent thru guidance computer, as long as data is not modified by this computer.
  - If processed in guidance computer, this becomes safety critical (it is expensive and cumbersome to safety certify guidance logic devices)
  - Having raw data processed by fuze logic is not considered cost driver or design complication
  - If using more than one logic device, should strive to implement in such a manner that only one is safety critical
- **Preference is always to have separate environmental and guidance sensors**
- **BIT Checks:**
  - AFSRB prefers that these be limited to continuity checks only – does not support exercising of safety features or powering up of logic beyond what is needed to verify continuity

- **Safety Features**

- **Must be independent:**

- Independent means that the failure or subversion of one safety feature does not affect performance of the other safety feature(s)
    - Also means they must sense different environments (i.e., velocity and acceleration are not different)
      - Two physically independent setback locks would not be allowed (exception: multi-stage rockets or missiles where separate G-T profiles are gated with an interstagial time window)

- **Must be, where possible, environments instead of events that occur in munition or signals derived from events.**

- Events include reaching apogee, generation of “good guidance” signals, umbilical disconnect, deployment of control surfaces, firing of side thrusters, etc.
    - If events are used where a second environment is difficult at best to sense, they should be gated with some logic associated with the event (i. e., time window)



- **Safe Separation**
  - **For the AFSRB:**
    - **Safe Separation is defined as the distance from the munition to the launch crew where there is a  $1 \times 10^{-4}$  probability of the crew taking a hit from a fragment that has a 50% chance of breaking exposed skin**
    - **Is based on munition fragmentation pattern and has nothing to do with fuze functioning**
    - **Is different than Safe Escape for an aircraft, the fuze arming distance, and the minimum engagement distance**

# ESA DESIGN GUIDELINES

- **With STANAG 4187 Ed 4, three switches (energy breaks) are now mandatory: two static and one dynamic**
- **No single environment or event signal can be used to enable more than one static switch**
- **Multiple signals can be used to enable more than one static switch**
- **The circuit which controls operation of the arming switches shall be physically partitioned into at least two elements, none of which are capable (by virtue of circuit architecture and partitioning, not element design) of independently arming the system.**
- **The functional partitioning shall be immune to being bypassed by electrical, mechanical, and thermal environmental hazards.**

- **A second safety feature (static switch) shall not be configured as the mechanical equivalent of a lock on a lock.**

## **Dynamic Switch**

- **The circuit driving the dynamic switch shall be designed so that any failure modes of that circuit should not lead to a situation where the switch defaults to a gated fixed frequency free running oscillator**
  - **System clocks operating at frequencies that may drive the dynamic switch are not allowed to be part of the S&A design**
- **The dynamic arming switch, when configured as an integral part of the high voltage converter, should be so configured that any static failures disable the converter.**

# COMMAND-ARM FUZING

- New capability driving fuze designs for use in urban combat environments, and to defeat enemy positioned behind obstacles
- **Has become a more common fuze architecture**
- Primarily medium caliber – is really implemented as command arming + functioning of a fuze
- Need precise bursting point due to relatively small warhead footprint, or to defeat target
- Probably will be firing over the heads of friendly forces



- Requires capability of air bursting anywhere along the projectile's trajectory beyond minimum engagement
- Minimum engagement distance can be within safe separation distance
- Target distance/setting info input to fuze via fire control system
- Preference is to protect friendly troops along trajectory and/or near target to the greatest degree possible
- Some traditional fuze solutions either not accurate enough or did not provide overhead safety

- Preferred solution is to incorporate an approach where fuze is arm-enabled by sensing launch environments and then command armed/functioned at burst point. For final arming, preferred approach is to release interrupter with stored energy device and use available flight environments to move interrupter into armed position.
- The AFSRB accepted the use of a piston actuator to move the interrupter into the armed condition, after the interrupter had been unlocked. The piston actuator defeats a shear tab that acts as a safety feature in the form of a blocking device.

- In the absence of a spin lock, the use of a piston actuator overcoming a shear tab violates a tenant and an objective of the safety standards:
  - Dual safety – shear tab is a block, not a lock
  - Use of stored energy in arming of the interrupter
- The acceptance by the Board was based on:
  - Rigorous testing of the shear tab, to include jolt and jumble with the setback lock missing
  - Historical evidence that piston actuators of this type do not fail by pre-firing without the correct signals and power

- The setback lock would prevent shearing of the tab and keep the interrupter safe if the P/A pre-fired with setback lock in place
- That under any credible environmental mishap or other accident at least two safety feature failures would be required in order for the interrupter to be released
- That testing to AOP-20/MIL-STD-331 environments indicated no safety issues

## Challenge to the fuze community:

Is there a better way to do this?

# ORIGIN OF THE 500 VOLT REQUIREMENT



## MIL-STD-332 (MUCOM) 14 May 1969:

- Paragraph 5.1.3.2 –
  - When the explosive train does not contain primary explosives, (e.g. EBW), interruption, shielding, and other protection, the initiation system must be designed to provide at least the same degree of fuze safety obtained with an interrupted train employing primary explosives.

## MIL-STD-1316 (Navy) 16 June 1967:

- Paragraph 5.1.3 –
  - Electric initiators “in-line” – Electric initiators “in-line” (i.e., not followed by explosive train interruption) shall not be used in fuzes even though explosives employed are those listed in 5.1.2.

## MIL-STD-1316A (17 September 1970)

- 4.2 Initiators “in-line”. - Initiators “in-line” (i.e., not followed by explosive train interruption) shall not be used in fuzes, **except as allowed by paragraph 4.2.2 below**, even though explosives employed are those listed in 4.1.2. **Where electrical type initiators or detonators are employed, a positive means (e.g., shorting or switching) of preventing fuze detonation prior to fuze arming shall be provided.**
- 4.2.1 When the explosive train does not contain primary explosives (e.g. Exploding Bridgewire (EBW) per MIL-I-23659), and has no provision for interruption, shielding, and other protection, then the initiation system shall be designed to provide at least the same degree of fuze safety, **including a mechanical interruption in the electrical circuit**, as is obtained with an interrupted train employing primary explosives.

## MIL-STD-1316A (17 September 1970)

- **4.2.2 EBW Devices.** – Exploding bridgewire (EBW) devices may be used without subsequent explosive train interruption if the following conditions are met:
  - a. The explosive initiated by the exploding wire is an explosive listed in 4.1.2.
  - b. The arming and triggering signals for initiating the EBW device are switched by two independent features requiring independent sources of energy from an environmental force for operation.
  - c. One of the mechanisms in (b) above shall derive its energy from an environmental force after launch.
  - **d. The sensitivity of the EBW device to electrical initiation is not greater than Group B per MIL-I-23659. The device cannot be initiated by any electrical signal at a peak potential of 500 volts, nor can a 500 volt discharge, especially from the firing circuit capacitor, initiate the device.**

## MIL-STD-1316B (15 February 1977)

- *Eliminated Non-Interrupted Explosive Train discussion from the requirement sections*
- Paragraph 7.2 In-Line Explosive Systems (in the NOTES section):
  - The use of an in-line explosive system which does not meet the requirements of explosive train interruption, may be necessary or very desirable for future systems to simplify an otherwise overly complex system or to solve a unique set of safing, arming and firing requirements. **For in-line systems, the basic safety requirements and the methodology for demonstrating that an acceptable level of safety is achieved, HAVE NOT BEEN ESTABLISHED.**
  - If in a future weapon, an in-line explosive is the preferred approach, the development of the system will include the establishment of safety requirements and procedures for demonstrating that the required safety is achieved. The following is a list of some of the major conditions which should be met if an in-line system is developed.

## MIL-STD-1316C (3 January 1984)

- Paragraph 4.3.4 Non-interrupted explosive train control. **When the explosive train contains only those explosive materials allowed by 4.3.1, no explosive train interruption is required. One of the following methods of controlling function energy shall be employed to preclude arming before safe separation.** Additionally, the fuze design shall include positive means to prevent the fuze from being assembled without its energy control feature(s). The combined probability of having minimum function energy in the fuze, having a failure of the energy control feature(s) and firing the initiator with minimum function energy must be compatible with the specified fuze safety system failure rate (see 4.6).
  - a. For fuzes containing minimum non-electrical function energy prior to safe separation, at least one energy interrupter directly and mechanically locked in the safe position by at least two independent safety features shall prevent the flow of energy to the initiator.
  - b. For fuzes containing minimum electrical function energy prior to safe separation, at least two energy interrupters directly and mechanically locked in the safe position, each by an independent safety feature, shall prevent the flow of energy to the initiator.
  - c. For systems using techniques for accumulating functioning energy from the post-launch environment, the fuze shall not permit any functioning energy to reach the initiator until verification, by the fuze, of a proper launch, and attainment of a safe separation distance. Additionally, any energy of the type required to function the initiator which exists in the fuze prior to safe separation shall be less than the minimum function energy.

## MIL-STD-1316C (3 January 1984)

- 4.3.5 Electrical sensitivity. The initiator for an electrically fired non-interrupted explosive train shall meet the characteristics listed for Class B initiators of MIL-I-23659. *The initiator shall not be capable of being functioned by any electrical signal at a potential of less than 500 volts.* Electromagnetic emission sensitivity and susceptibility of the fuze shall not create a hazard. The requirements of MIL-STD-461 (and DOD-STD-1463 for the Army) shall apply.
- More severe requirement than MIL-STD-1316A
- Based on experience with EBWs?



## MIL-STD-1316D (9 April 1991)

- **5.3.4.1 Electrical initiator sensitivity.** The initiator for an electrically fired non-interrupted explosive train shall:
  - a. Meet the characteristics listed for Class B initiators of MIL-I-23659.
  - *b. Not exhibit unsafe degradation when tested in accordance with MIL-STD-1512.*
  - *c. Not be capable of being detonated by any electrical potential of less than 500 volts.*
  - *d. Not be capable of being initiated by any electrical potential of less than 500 volts, when applied to any accessible part of the fuzing system after installation into the munition or any munition subsystem.*
- **More severe requirement than MIL-STD-1316C**

- **Believe intent was to prevent use of EBW initiators in-line with secondary explosives.**
- **Due to low voltage sensitivity of these types of initiators.**
- **But, why 500?**
- **Believe nothing to do with 400 VDC available shipboard, as has been suggested.**
- **Lowest voltage everyone present could agree to.**
- **Should the 500 V requirement be left unchanged?**



- **Should the 500 V requirement be changed?**
  - **To what?**
  - **No compelling argument to change it**
  - **Precedent to change it again**
  - **Need a threshold**
  - **If changed, no longer a threshold, but a variable**

# MIL-STD-1316F & STANAG 4187 Ed 4



- In Tri-Service Approval process
- Will now be a supplement to STANAG 4187 Edition 4
- Will now have a dual-standard system for safety design guidelines
- Intend to brief at next year's conference
- Both documents will be available on ASSIST
- Similar situation for:
  - STANAG 4497 Edition 2 and MIL-STD-1911B
  - STANAG 4368 Edition 3 and MIL-STD-1901B



- **New version of Guidance for AFSRB Safety Certifications, dated April 2011**
- **For copies, contact:**
  - **Chris Janow at:**  
**chris.janow@us.army.mil**  
**973-724-5438**

- **AFSRB staffed for and focused on providing the “safest” fuzes for our Warfighters**
- **AFSRB is a “Gatekeeper” group that provides safety reviews of products going to the field**
- **Ultimately, safety is the responsibility of the MDA, the PM and the Project Team**
- **The AFSRB will work with the Project Team to assure safety is achieved**
- **The AFSRB will be integral part of joint weapon systems safety reviews**

- **Command – Arm fuzing is becoming a common type of fuze architecture**
- **Can't figure out a way to meet requirements without the use of a stored energy device**
- **AFSRB has accepted concept of using a piston actuator to overcome a blocking type of safety feature in these designs in order to provide overhead safety**
- **Origin of the 500 volt requirement as a threshold – used to prevent use of EBWs**
- **Do not think it should be modified**
- **Contact Info:**
  - **Chris Janow**                      973-724-5438

[chris.janow@us.army.mil](mailto:chris.janow@us.army.mil)

# ***DTRA Counter WMD Technologies Fuzing & Instrumentation Technology Overview***

***Presented at  
55th Annual NDIA Fuze Conference  
May 2011***

***Danny R. Hayles***





# Outline

- Mission
- Requirement for Hard Target Fuzing
- Current Fuzing and Instrumentation Technology Thrusts
- Summary



# DTRA Mission

- Mission:
  - ...reduce the threat to the United States and its allies from Weapons of Mass Destruction (CBRNE) by providing capabilities to reduce, eliminate, and counter the threat, and mitigate its effects.
- Functions:
  - Conduct RDT&E programs...in areas related to WMD and designated advanced weapons to include...WMD-related targets and the entire class of hard and deeply buried facilities.
- Vision:
  - Develop, test, and demonstrate to the Warfighters reliable and effective solutions to defeat WMD and WMD-related functions protected in Hard and Deeply Buried Targets





# Hard & Deeply Buried Target (HDBT) Defeat Critical to Counter WMD Mission

- Use of HDBTs is widespread among both hostile states and terrorists to protect WMD and WMD-related functions including:

- Production, storage, research
- Delivery systems
- Command and control
- National/terrorist leadership

**MOST  
VALUABLE  
ASSETS**



***You can't defeat WMDs, if you  
can't defeat HDBTs!!***

***You can't defeat HDBTs, if the  
fuze does not survive!!***





# Fuzing and Instrumentation Technology Vision

- Develop and demonstrate innovative **survivable** fuze and instrumentation technologies to support the defeat of **hard** WMD related facilities
  - Robust Fuzewell Instrumentation System (RFIS)
  - Sub-scale Survivability Test Protocol
  - FMU-152 Baseline Survivability Assessment (BSA)
  - 3-Axis DTRA Data Recorder Advanced Miniaturization (3DDR-AM) Universal Booster Cup Recorder



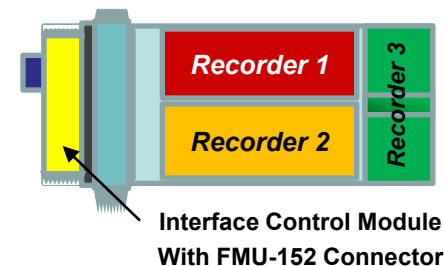


# Robust Fuzewell Instrumentation System (RFIS)

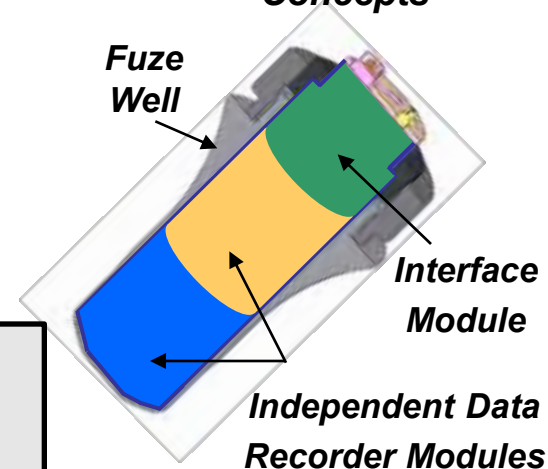
- Collaborating with AFRL/RW to develop a shock survivable data recorder instrumentation package with redundant internal data recorders to fit in standard 3" fuzewell
  - 27 month contract awarded to ATK for prototype development and delivery concludes January 2013
  - Support CONOPS for laboratory, sub-scale cannon, and full scale sled and flight testing
  - Provide electrical/mechanical ICD for internal recorders
  - Successful System Requirements Review (SRR) and System Functional Review (SFR) , Preliminary Design Review in June 2011

## RFIS Prototype Features

- Internal infrastructure supports up to 3 recorders
- To be delivered with modified commercially available recorders
- JPF compliant interface for external control of recorders
- Will provide battery power for internal recorders
- Modular design supports recorder installation and removal by trained technician



## ***Notional RFIS Concepts***

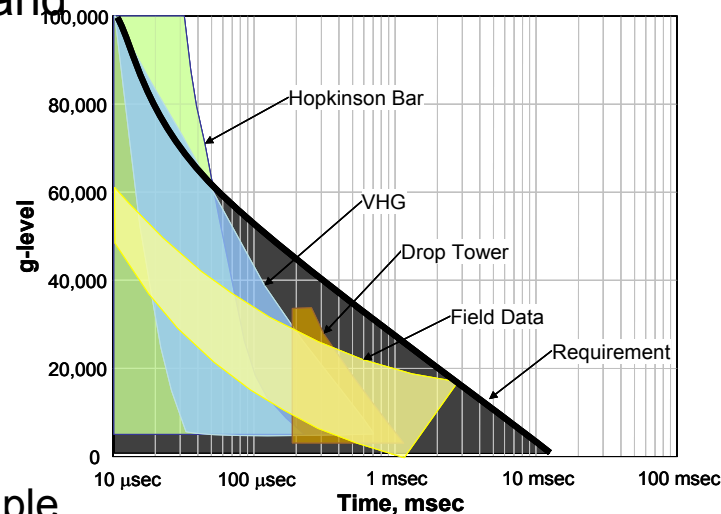




# Sub-scale Survivability Test Protocol

- Joint research program with AFRL/RWMF to develop a Fuze Survivability Protocol (FSP)
  - Test series developed to replicate portions of full-scale impact environments using laboratory and field test equipment
- FSP Version 1.0
  - Test protocol defined and tested in FY10
  - VHG and Drop Tower testing conducted
- FSP Version 2.0
  - Refinement of initial FSP
  - Protocol tests based on impact data from multiple systems and targets
  - Initial testing began in early FY11

**Notional Shock Spectrum**



*Photo Courtesy of AFRL/RWMF  
Public Releasable: AAC/PA 03-496*



# FMU-152A/B Baseline Survivability Assessment (BSA)

- Joint research program with AFRL/RWMF & Kaman Precision Products
  - FMU-152A/B fuze used to establish a survivability baseline for the Fuze Survivability Protocol (FSP)
- Phase 1 Survivability Testing
  - FMU-152A/B LAT units completed testing in 3<sup>rd</sup> & 4<sup>th</sup> qtr FY10
  - Tested using FSP version 1.0
- Phase 2 Survivability Testing
  - Testing to begin in 3<sup>rd</sup> qtr FY11
  - LAT units tested using FSP version 2.0
  - Baseline testing anticipated to be completed by 1<sup>st</sup> qtr FY12



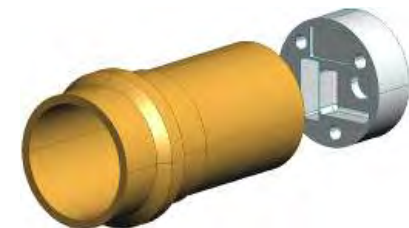
*Photo Courtesy of AFRL/RWMF  
Public Releasable: AAC/PA 03-496*





# 3DDR-AM Universal Booster Cup Recorder

- Collaborating with Sandia National Lab (SNL) to develop the 3-axis DTRA Data Recorder Advanced Miniaturization (3DDR-AM) shock survivable data recorder designed for the booster cups of legacy and developmental munitions
  - Design requirements based on a super set of hard target defeat inventory and EMD fuzes
  - Design based on 3DDR brassboard
  - Exploit miniaturized electronics, improved packaging techniques, and reduced power requirements of miniaturized electronics
  - Replaceable batteries (fast test turnaround)
  - Replaceable accelerometers (primary failure mode)
  - Functional and physical models have been developed, and physical model has been validated against system technical requirements





# ***Fuzing and Instrumentation Technology Vision***

- Develop and demonstrate innovative **survivable** fuze and instrumentation technologies to support the defeat of **hard** WMD related facilities
- Develop and demonstrate innovative fuze technologies to support the defeat of WMD related facilities using **non-penetrating** munitions.







# *Fuzing for Non-penetrating Munitions*

- Wide spectrum of possible WMD targets requires a wide variety of fuzing technologies and capabilities beyond classic penetrating fuze mounted in the fuzewell:
  - Distributed sensing
  - Non-traditional sensors
  - Modular and distributed fuzing
  - Scalable effects based fuzing





## Summary

- Hard target **survivable** fuzing is critical to Counter-WMD mission
  - Hardened or deeply buried facilities have become:
    - More important to potential adversarial nations and non-national organizations
    - Harder to defeat
  - Smart post-impact fuzing essential to defeating HDBTs
    - Provides optimum burst point control
  - Fuze harsh environment characterization is essential
    - Predictive test and modeling capabilities for fuze/fuze component survivability
    - Requires reliable, survivable, multi-purpose instrumentation
- Need for non-traditional fuze technologies and capabilities to defeat wide variety of WMD targets
  - DTRA pursuing a more balanced fuzing portfolio

**WMD defeat requires more than just hard target fuzing**

# FIPS 140-2 Tamper Detection to protect Fuze Technology

---

Douglas Cox, Trong Huynh,  
John Ambrose

Presented at the 55th Annual  
Fuze Conference in Salt Lake  
City, Utah on May 25, 2011

by Douglas Cox  
[info@mix-sig.com](mailto:info@mix-sig.com)

Mixed Signal Integration

2157F O'Toole Avenue

San Jose, CA 95131

+1 408-434-6305

[www.mix-sig.com](http://www.mix-sig.com)



# What is F.I.P.S.

---

- Federal Information Processing Standard
  - 5 Levels of Protection
  - Level 1 is Cryptography
  - Level 2 is Physical protection
  - Level 3 is Voltage and Reset protection
  - Level 4 is Temperature monitoring +Level 3
  - Level 5 is Current monitoring protection +Level 4



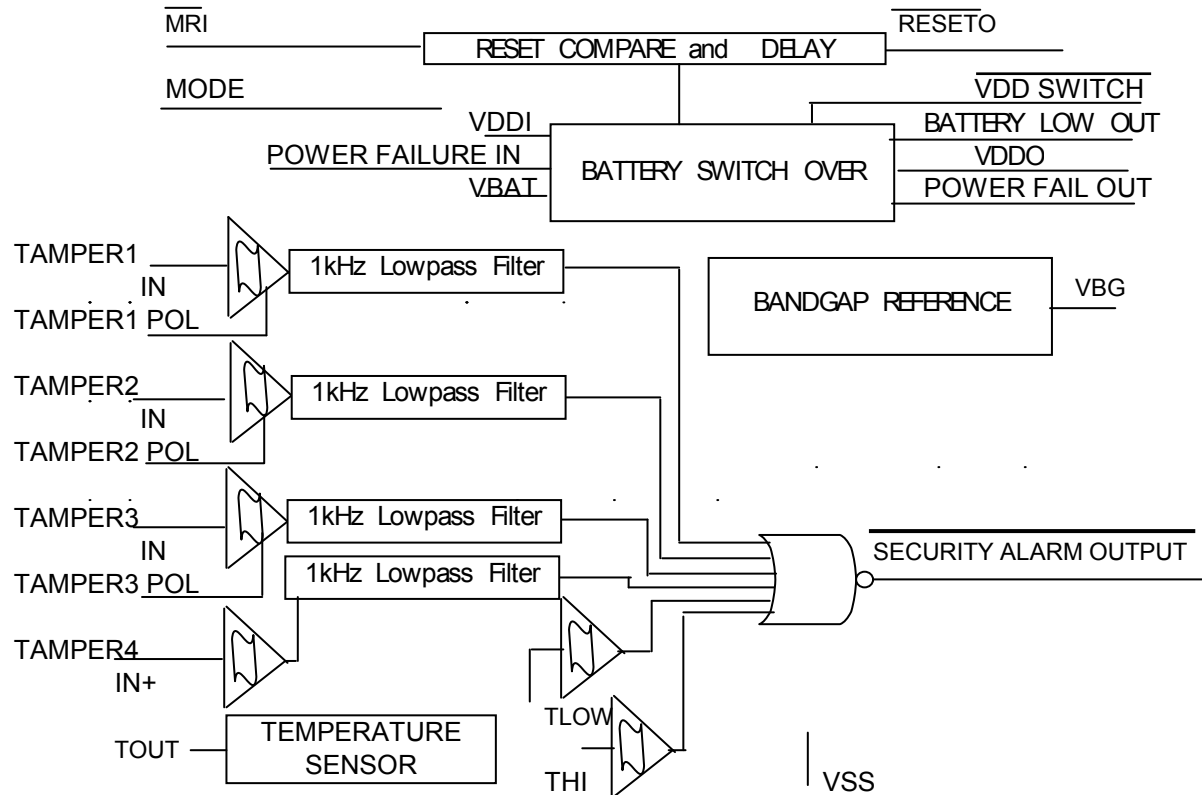
# The Problem

---

- Fuze Technology needs protection
  - Sophisticated Analog and Digital Signal Processing techniques
  - Danger of reverse engineering
  - No battery drain
  - Tampering with Fuze ignition sequence
  - Tampering with Safe and Arm



# MSI's MSFIPS provides Monitoring Functions





# System Design

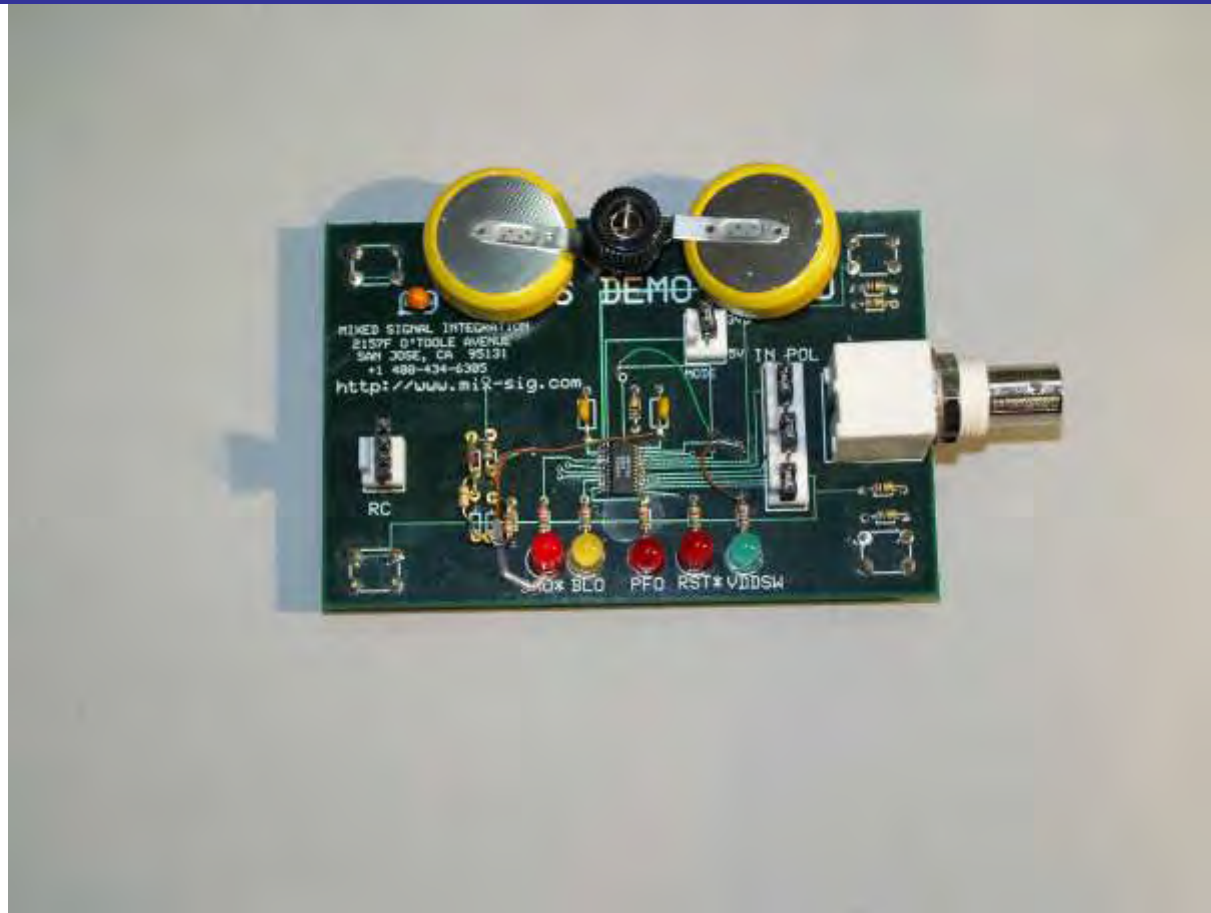
---

Life of Lithium Battery with no drain is ~10 years.

- To increase life, switches for access power the MSFIPS.
- Once case is opened, MSFIPS would monitor status.



# MSFIPS Evaluation Board



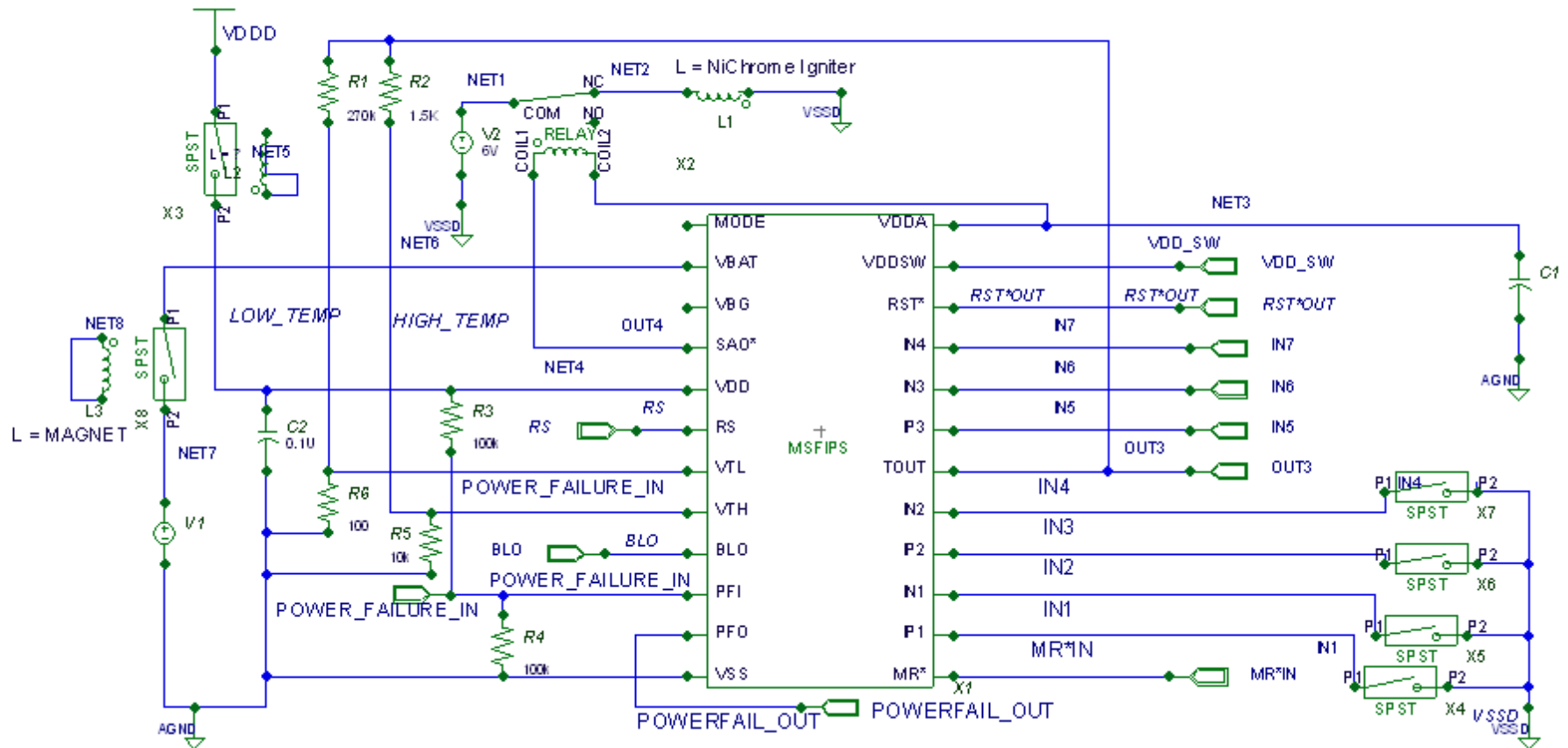
# What if Triggered?

---

- SAO\* goes low closing relay to igniter.
- 50 gauge NiChrome© wire requires only 500 mA current.
- Able to burn and damage components to prevent reverse engineering.



# Simplified Schematic



# Technical Issues

---

- Position of the tamper switches
  - Ensure they cannot be bypassed
- Selection of temperature range
  - Need to be set for range found in outdoors
- Ensuring destruction of fuze technology is complete.



# Summary

---

MSFIPS provides monitor and protection to  
Fuzing technology

- Monitors tampering.
- Monitors typical hacking techniques
- Triggers destruction of fuze technology.







*Presented to:*  
**55<sup>th</sup> Annual Fuze Conference**  
National Defense Industrial Association  
Salt Lake City, Utah

***Simple Optical Sensors  
for Firing Tests***



DISTRIBUTION STATEMENT A. Approved for public release; distribution unlimited. Review completed by AMRDEC Public Affairs Office 24 May 2011; FN5292.

***TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.***

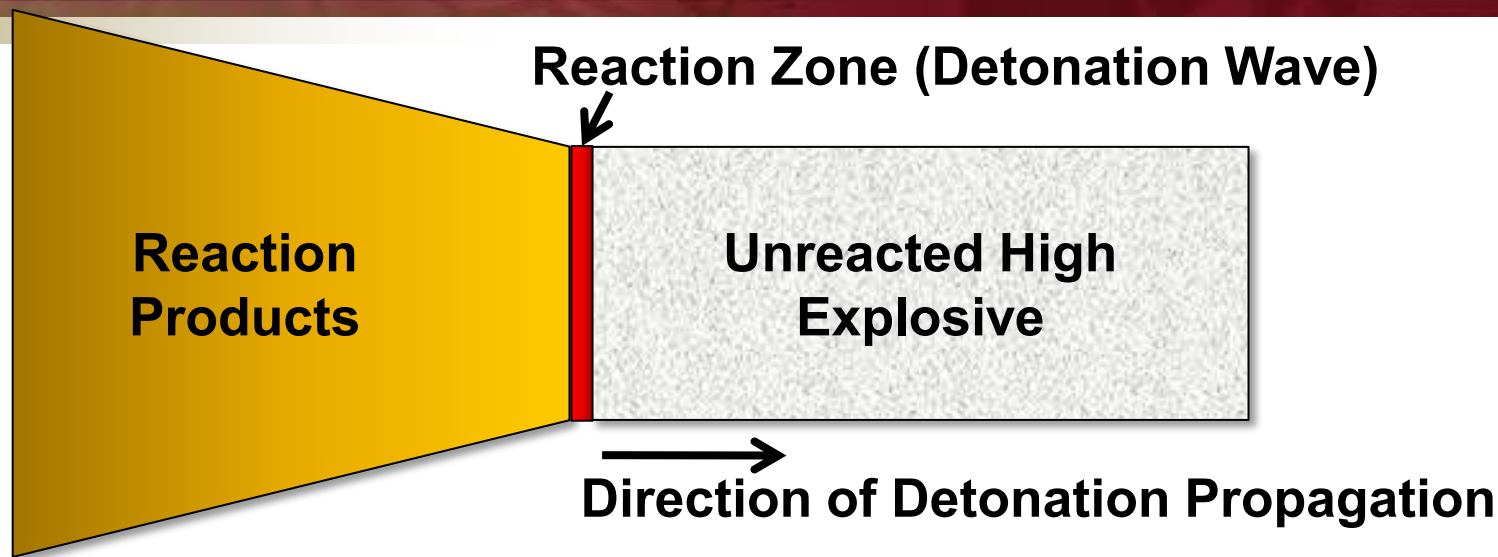
May 25, 2011

*Presented by:*  
**Michael P. Connolly**  
Electronics Engineer  
Aviation and Missile Research,  
Development and Engineering Center

- **No statement or information in this presentation is to be regarded as an official policy, position, guidance, recommendation, or direction of the United States (US) Government.**
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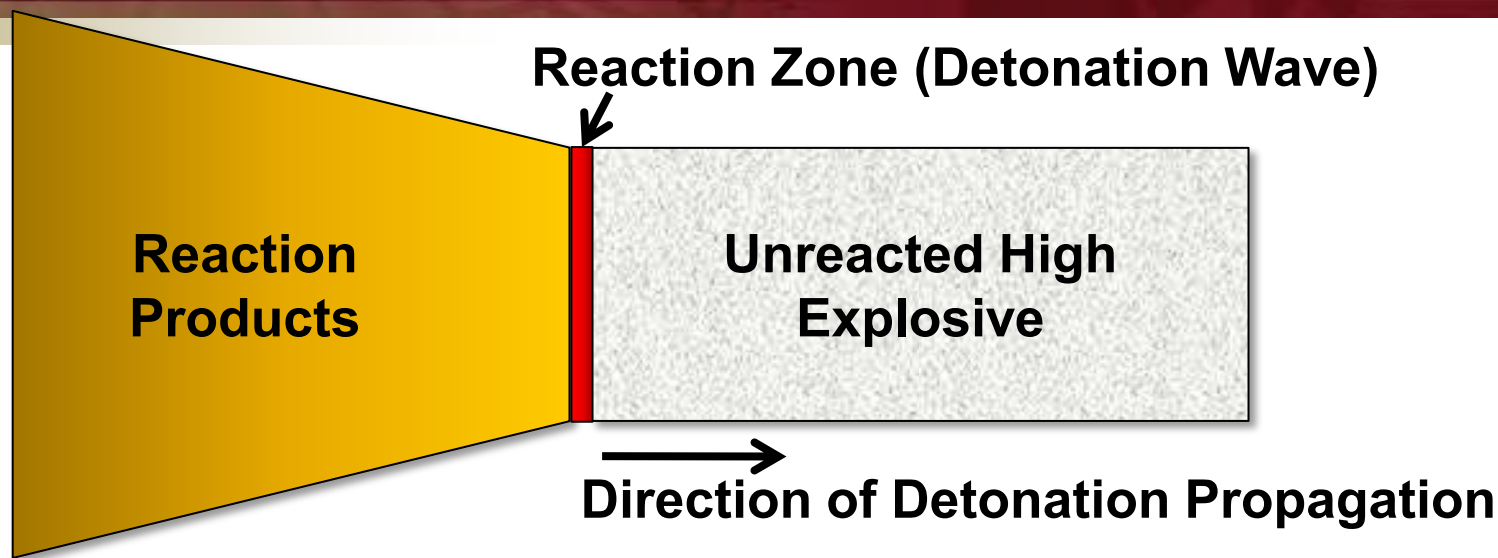
- **Background & Requirements**
- **Potential Solutions**
- **Approach**
- **Apparatus**
- **Findings**
- **Future Work**

- John Dunbar, Ecosse Design LLC
- AMRDEC:
  - Devin Chamness
  - Will Goins (Dynetics, Inc.)
  - Kirby Holtam
  - Dr. Jay Land
  - Daniel Pitts
  - Anthony Steele
  - Matt Stubbs (Dynetics, Inc.)
  - Allen Stults
  - Justin Sweitzer (CGI Federal)
  - Ben Sweitzer (CGI Federal)
  - Ben Thomason
- Brad Hanna, Naval Surface Warfare Center-Dahlgren Division
- Ken Jensen and Chuck Treu, Kansas City Plant



## *What can we measure?*

- Sensitivity
- Combustion
- Working Capacity
- **Detonation**

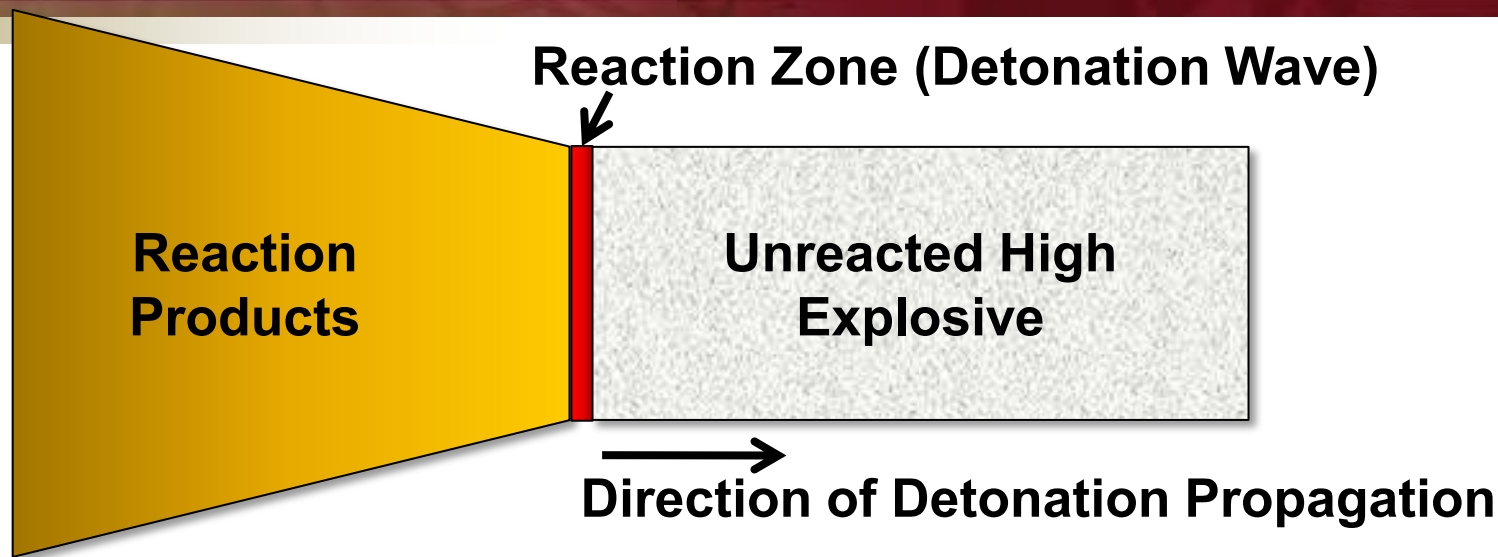


## *What can we measure?*

- Sensitivity
- Combustion
- Working Capacity
- **Detonation**

### Parameters

- **Reaction or no reaction.**
- **Velocity**
- Pressure
- Temperature
- Products"Composition



### *What can we measure?*

- Sensitivity
- Combustion
- Working Capacity
- **Detonation**

#### Some Techniques

- Streak / Framing Camera
- Schlieren / Shadowgraph
- Flash X-Ray Radiography
- VISAR
- PDV
- Fabry-Perot
- Conductive Probes
- Piezoelectric Probes
- Optical Fiber Probes



## Want to measure:

- Reaction or no reaction.
- Velocity

- Streak / Framing Camera
- Schlieren / Shadowgraph
- Flash X-Ray Radiography
- VISAR
- PDV
- Fabry-Perot
- Conductive Probes
- Piezoelectric Probes
- Optical Fiber Probes

## “Intrinsic” Requirements

- Accuracy
- Precision
- Sensitivity & Dynamic Range
- Calibration
- Channel Independence
- Intrusiveness
- Data Requirements

## “Extrinsic” Requirements

- Cost (initial & recurring)
- Compatibility w/ existing equip.
- Skills required to use & maintain.
- Experimental Environment(s)

## Want to measure:

- **Reaction or no reaction.**
- **Velocity**

- **Streak / Framing Camera**
- **Schlieren / Shadowgraph**
- **Flash X-Ray Radiography**

- **VISAR**
- **PDV**
- **Fabry-Perot**

- **Conductive Probes**
- **Piezoelectric Probes**
- **Optical Fiber Probes**

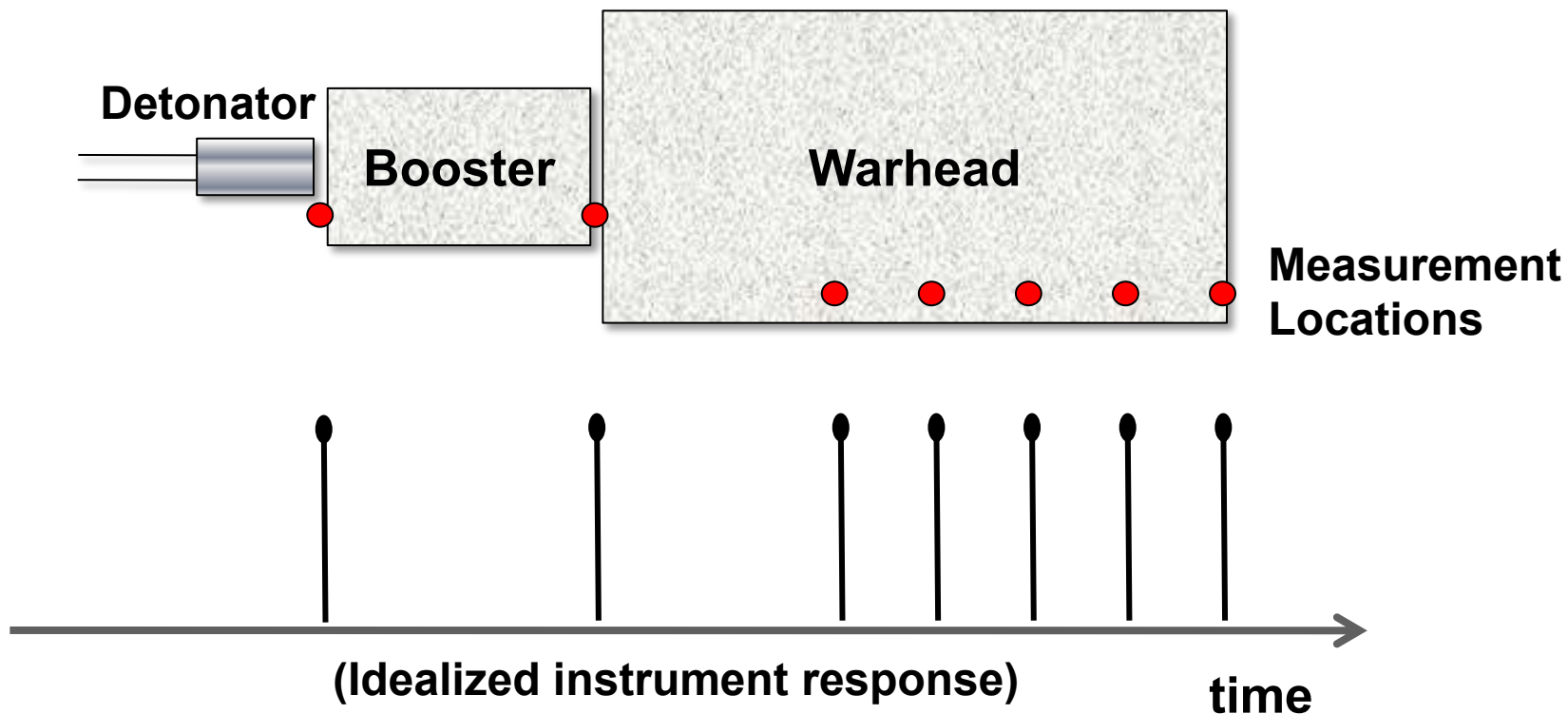
## “Intrinsic” Requirements

- **Accuracy**
- **Precision**
- **Sensitivity & Dynamic Range**
- **Calibration**
- **Channel Independence**
- **Intrusiveness**
- **Data Requirements**

## “Extrinsic” Requirements

- **Cost (initial & recurring)**
- **Compatibility w/ existing equip.**
- **Skills required to use & maintain.**
- **Experimental Environment(s)**

Measure the timing of the detonation wave as it propagates through the experimental specimen.



## Conductive Probes

- Make / Break Switches
- Nichrome Wire
- Ion Pins

## Piezoelectric Probes

- PVDF
- PZT

## Optical Fiber Probes

- Optical Fiber
- Optical Fiber with Lens
- Modified Fiber

## Potentially offers:

- Accurate, fast response.
- Channel independence.
- Scalability.
- Favorable Electromagnetics.

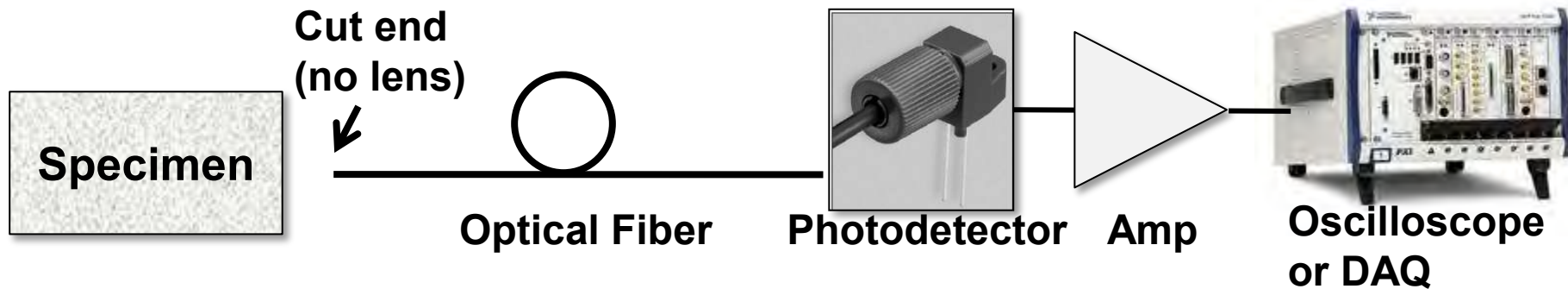
Refs: Test Methods for Explosives [Suceska1995]

High speed velocity measurements on an EFI-system [Prinse2007]

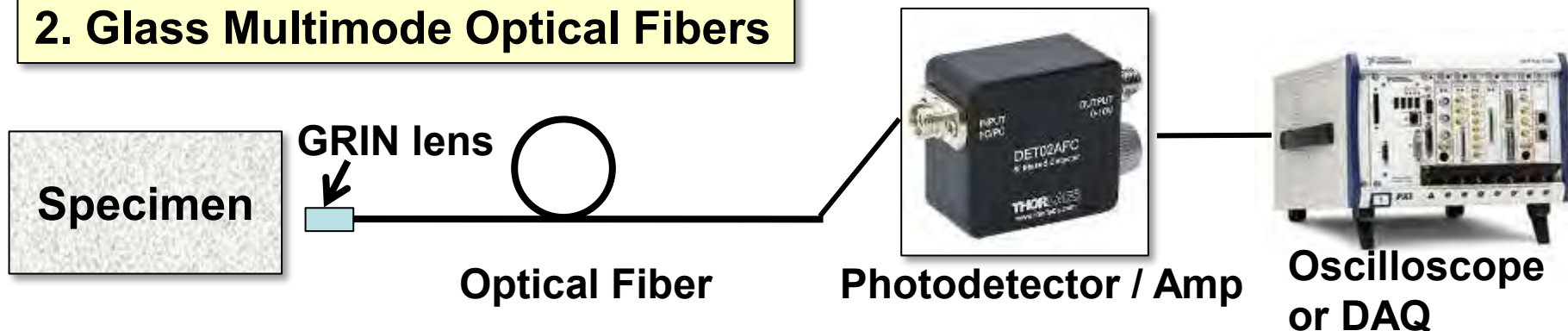
Dynasen, Inc., <http://www.dynasen.com>

Measurement Specialties, Inc., <http://www.meas-spec.com/> **TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

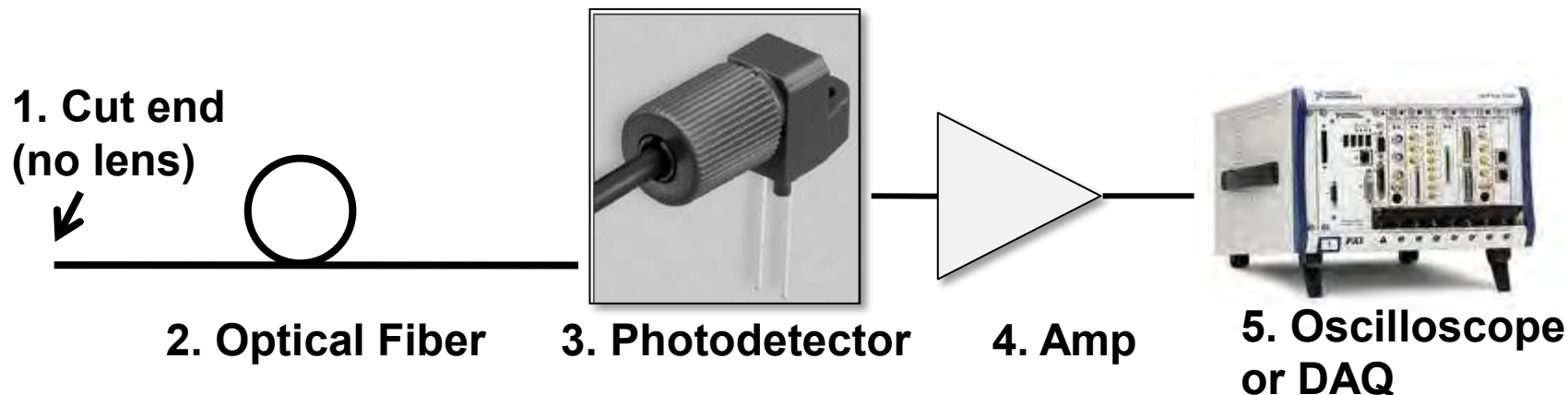
## 1. Plastic Multimode Optical Fiber Probe



## 2. Glass Multimode Optical Fibers

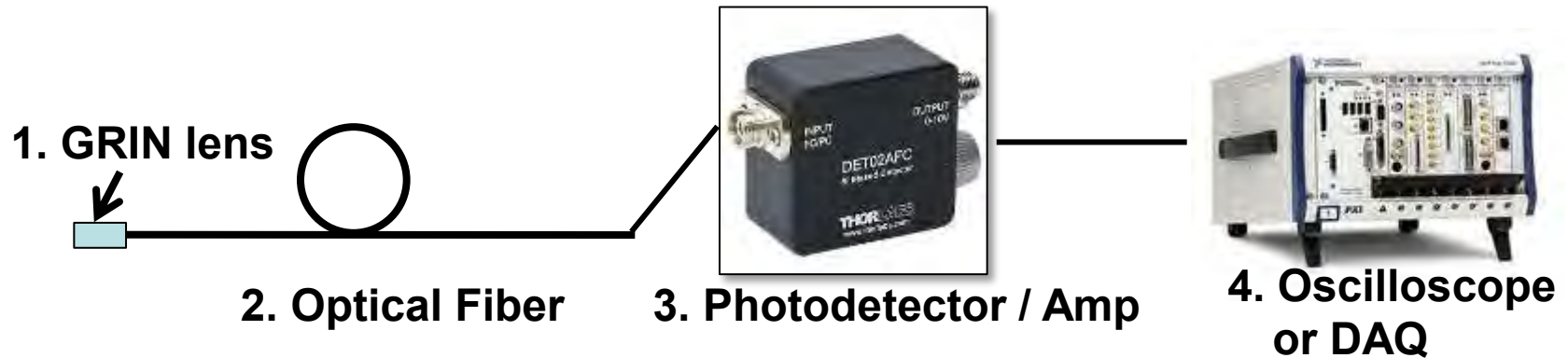


Refs: Laser Light Scattering: Principles and Practice, Second Edition [Chu2007]  
High speed velocity measurements on an EFI-system [Prinse2007]  
Fiber Optic Sensors: An Introduction for Engineers and Scientists [Udd1991]  
Electro-Optics Handbook, Second Edition [Waynant2000]



1. Use a razor or craft knife to make a clean cut perpendicular to jacket.
2. Tyco Electronics, p/n 501232-4, step index multimode fiber, polyethylene jacket, PMMA fiber:  $n_{\text{core}}=1.49$ ,  $n_{\text{clad}}=1.42$ ,  $NA=0.46$ , Max atten 150db/km.
3. Industrial Fiber Optics IF-D91,  $t_r=5$  ns.
4. Amplifier as needed for signal conditioning.
5. Oscilloscope or Data Acquisition System (DAQ) as needed for data requirements.

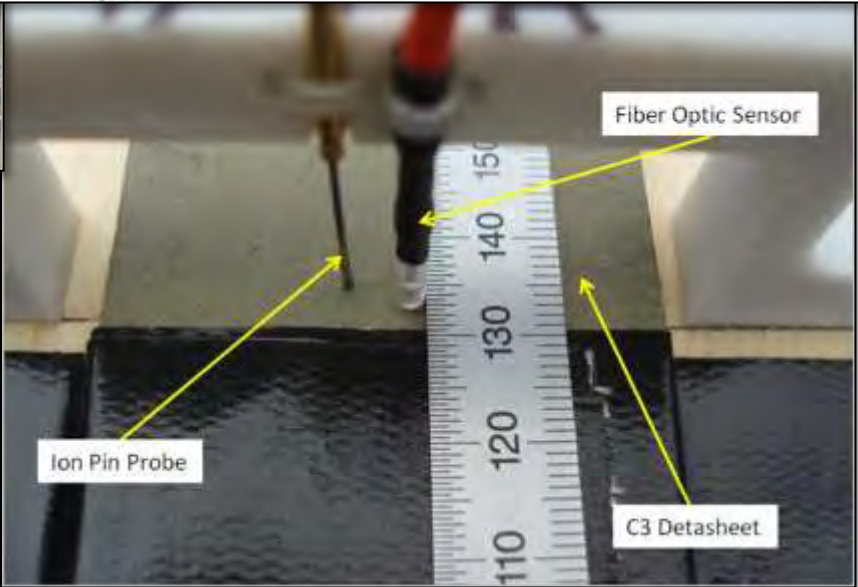
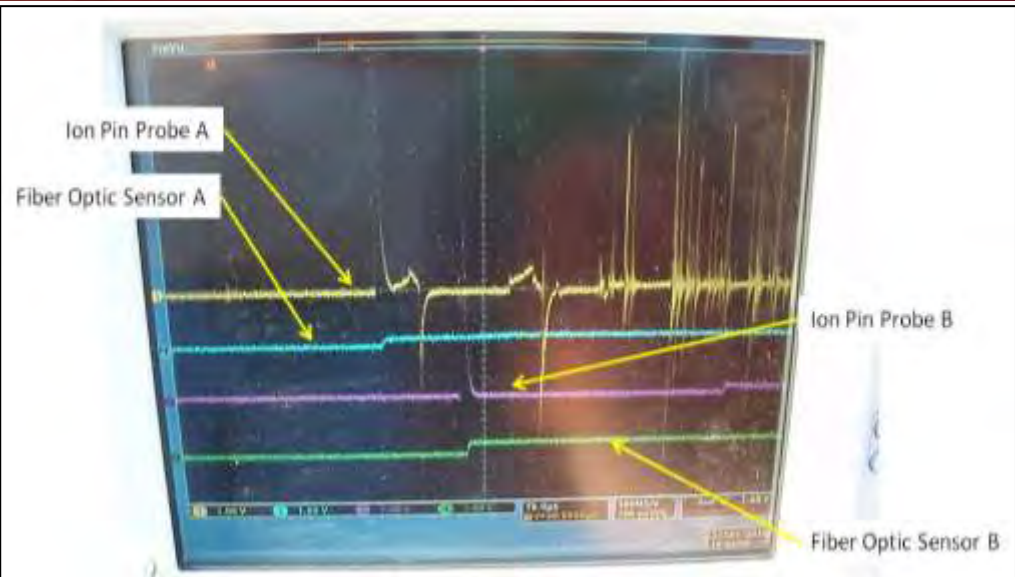
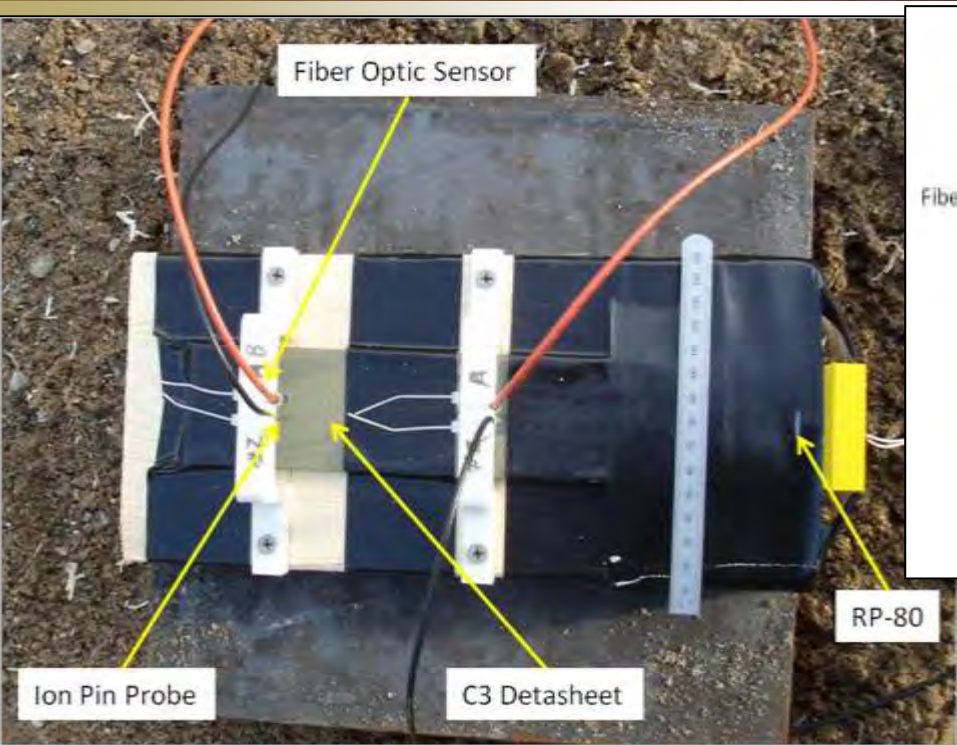
Refs: Tyco Electronics, <http://www.tycoelectronics.com>  
 Industrial Fiber Optics, <http://www.i-fiberoptics.com/>



1. GoFoton (formerly NSG America) SELFOC(tm) Gradient Index Lens, p/n SLW-180-023-SBC. Oxide glass, 0.23 pitch, gradient constant 0.332,  $N_0=1.5986$ .
2. Fiber Pigtail and Patch Cable. Optequip p/n A10006 and A20182. The fiber itself is Corning Infinicore 300 62.5/125 micron glass multimode fiber. Fiber end is first cleaved, inserted in ferrule (Thorlabs p/n 50-1800-126), and polished, and then the lens is attached using Norland optical adhesive number 61 (NOA-61), which is cured using a UV light source. Polished fiber NA=0.27. FC connectors used.
3. Thorlabs DET02AFC photodetector/amplifier. Si photodetector,  $t_r < 1\text{ns}$ .
4. Oscilloscope or Data Acquisition System (DAQ) as needed for data requirements.

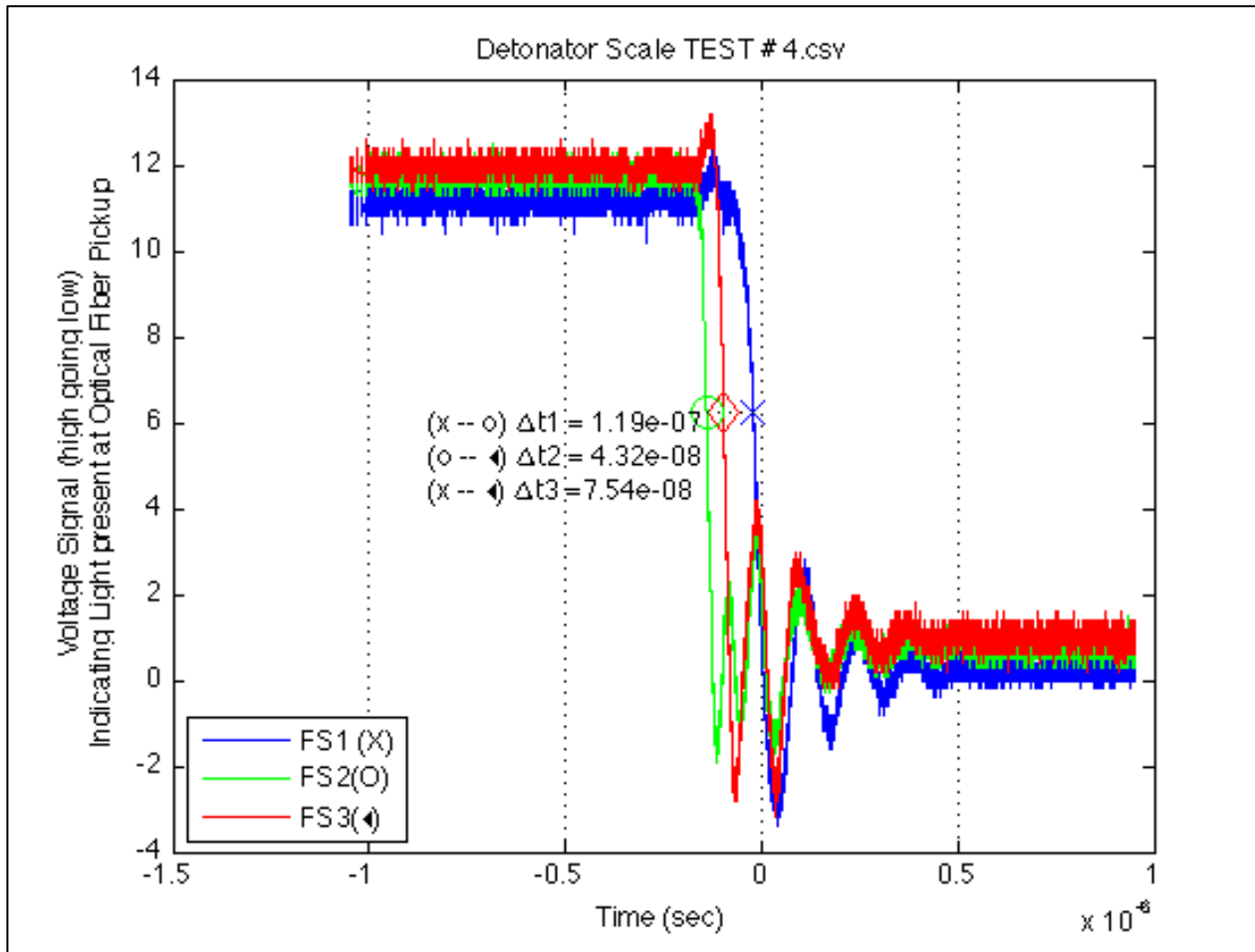
Refs: Corning, <http://www.corning.com/index.aspx>  
 GoFoton / NSG America <http://www.nsgamerica.com/>  
 Norland Products, Inc. <http://www.norlandprod.com/>  
 Optequip, <http://www.optequip.com/>  
 Thorlabs, Inc., <http://thorlabs.com/>





Test equipment included Tektronix DPO4101 Oscilloscope, a Dynasen model CS2-50-300 Pin Mixer to power the Ion Pin Probes, Two (2) Dynasen CA-1041 Ionization Pins, a laptop computer to record the data from the oscilloscope, two (2) Thorlabs DET02AFC Photodetectors, two (2) Fiber Optic Flash Sensors, and one (1) 100 meter multi-mode patch cable.

**Need to optimize system for fast, clean pulse response.**



**Total Delay  $T_D$**

$$T_D = \sum_{i=1}^n T_{Di}$$

**Total Rise Time  $T_R$**

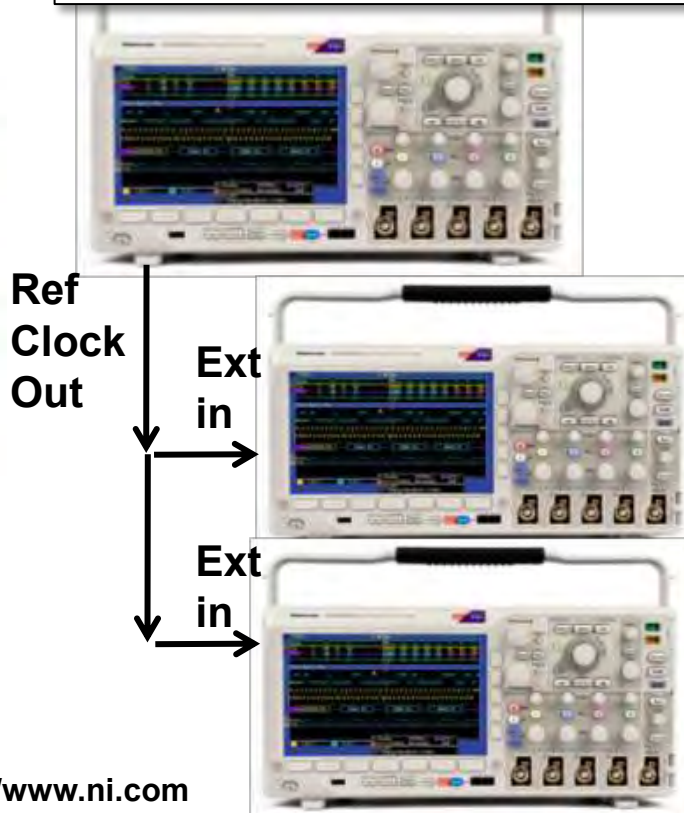
$$T_R = \sqrt{\sum_{i=1}^n T_{Ri}^2}$$

Scalability depends on common time reference across data record.

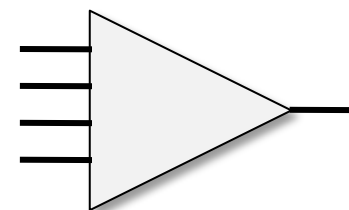
DAQ with many channels sync'd across bus.



Distribute common timing/trigger reference



Sum multiple inputs per channel



Refs: National Instruments, <http://www.ni.com>  
Tektronix, <http://www.tektronix.com>

Operational Amplifier Circuits: Theory and Applications [Kennedy1988]

**TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

- **More firing experiments (Summer 2011).**
- **Develop calibration / channel equalization technique.**
  - **Suitable for field as well as lab.**
- **Obtain or design high-speed amplifier with compensation for high-speed pulses.**
  - **Lowpass filter with Thomson/Bessel linear phase**
- **Survey alternative parts/suppliers.**



# Questions?

## Presenter contact information:

Mike Connolly

US Army Research, Development, and Engineering Command (RDECOM)

Aviation & Missile Research, Development, and Engineering Center (AMRDEC)

Redstone Arsenal, Alabama, USA

(256) 842-9579

[michael.p.connolly@us.army.mil](mailto:michael.p.connolly@us.army.mil)



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- Numerical Aperture Measurement of Graded-Index Optical Fibers, Method A, EIA/TIA-455-177A (FOTP-177).
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- U.S. Army Armament Research, Development, and Engineering Center (ARDEC) Fiber Optic Detonation Velocity Test, Technical Report ARMET-TR-09031, Brian Fuchs, Gerard Gillen, John Howell, Amy Wilson, January 2010, DTIC Accession no. AD-E403-252. *Unclassified, Restricted Distribution – US Government agencies and their contractors only.*



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High speed velocity measurements on an EFI-system, W.C. Prinse, P.g. van „tHof, L.K. Cheng, J.H.G. Scholtes, 27<sup>th</sup> International Congress on High-Speed Photography and Photonics, Proc. of SPIE 6279, 2007.

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# Scalable Software Evaluation Methodology and Tools

## A JFTP Proposal for FY12 Under FATG IV

Jeffrey M. Fornoff  
US Army RDECOM-ARDEC  
Picatinny Arsenal, NJ 07806-5000  
(973) 724-3014





# Purpose

---

- Fuzing designs are utilizing software in part or in whole in the implementation of one or more safety features in networked environments
- Safety critical software needs to be analyzed and tested to assure proper design and function
- No documentation exists to help identify all issues related to networked safety critical software in munitions.
- AOP-52 provides guidance in the requirements of design and implementation of safety critical software throughout the entire life-cycle, but not enough network guidance exists





# Background

---

- Implementation of Safety Features has evolved significantly
  - Mechanical (springs, setback weights, rotors, sheer pins)
  - Electronic (analog and/or simple digital circuits)
  - Software (microprocessor and/or programmable logic devices)
- The use of software has allowed designers the ability to design fuze safety features that are influenced partially or completely outside the fuze itself. The resulting “fuze chain” blurs the line between the fuze and the rest of the munition
- Recent standards and guidelines were developed to address software safety in fuzes, fuzing systems, and munitions - AOP-52 was developed under NATO AC326 Sub-group III with members of the US (DoD), UK, Germany, and France





# Case History

---

- Distributed fuze functions first encountered by the AFSRB with Spider hand-emplaced anti-personnel landmine
  - Arming completely controlled by a Remote Controlled Unit (RCU) (laptop PC) communicating with the Munitions Control Unit (MCU)
  - On-Off-On requirements made the software on the RCU safety critical (in addition to the software on the MCU)
  - Due to lack of suitable documentation at the time, software safety guidance was developed concurrent with the system design
- Lessons learned helped produce a better safety design with Scorpion
  - FESWG Guidelines on the use of Programmable Logic Devices
  - AFSRB Guidelines Appendix C
  - AOP-52





# Current Challenges

---

- Networked (remote controlled) munitions are becoming the “norm” given technology available today
- System of Systems allow remote arming/firing of weapons half-way around the world
- How does safety get designed into these advanced systems?
- What design parameters need to be addressed?
- What metrics can be identified to verify and test safety critical features?
- Bring to bear any existing software analysis techniques and/or tools – develop them if they don’t exist





# Proposed Work

---

- Identify safety critical parameters in a networked environment
  - Protocols (important for guaranteed communication)
  - Latency (important for real-time operations)
  - Quality of Service (QoS) (important for reliability & safety)
  - Data Integrity within networked communications and software
  - Information Assurance (IA) as it relates to safety
- Identify System of System integration issues affecting safety
- Create/augment guidance documents (i.e. update AOP-52)







## Proposed Work (continued)

---

- Perform research consulting with academia to identify safety critical parameters that need to be addressed in networked system designs
- Create a straw-man documentation that can be used to update AOP-52
  - Create a working group of SMEs from all the services
  - Work with NATO AC326 Sub-group III to update AOP-52
- Identify analysis techniques and/or tools that can be utilized to verify safety critical functions are properly designed and implemented





# Summary

---

- Research and identify networking parameters that affect software safety with the help of academia
- Update AOP-52 with respect to networking issues and provide additional guidance topics on System of Systems
- Identify software metrics affecting safety in network systems
- Identify and/or develop software analysis tools that can be used to test and verify safety critical metrics in network systems
- Identify scaling techniques and safety critical parameters when interfacing software in System of Systems





---

# Questions?



*Providing America Advanced Armaments for Peace and War*



# Backup Slides





# AOP-52 Contents

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- Executive Overview
- Introduction to the AOP
- Generic Guidelines and Requirements
- Software Safety Engineering
- COTS and NDI Software
- Testing and Assessment Guidelines
- References
  - Software Development Models
  - Lessons Learned
  - Process Charts





# Executive Overview

---

- Explains the need and importance of software safety elements in requirements and design of the program to managers and executives
- Software safety begins with program requirements and continues throughout the life-cycle of the program
- Even though software is only a part of the overall safety of a program, there are unique issues with software safety that need to be addressed





# Introduction to the AOP

---

- Explains the major purpose for the AOP
- Presents the scope of the subject matter incorporated in the document
- How the AOP is organized for maximum benefit of use
- Also includes:
  - Historical background
  - Problem identification
  - Introduction to the “Systems” approach







# Generic Guidelines and Requirements

---



- Introduction
- Determination of Safety-related Computing System Function
- Design and Development Process Requirements and Guidelines
- Software Design Verification and Validation
- System Design Requirements and Guidelines
- Computing System Environment Requirements and Guidelines
- Self-check Design Requirements and Guidelines
- Safety-related Computing System Functions Protection Requirements and Guidelines
- Interface Design Requirements
- Human Interface
- Critical Timing and Interrupt Functions
- Software Design and Development Requirements and Guidelines
- Software Maintenance Requirements and Guidelines
- Software Analysis and Testing





# Software Safety Engineering

---



- Introduction
- Software Safety Planning Management
- Software Safety Task Implementation
- Software Safety Testing and Risk Assessment
- Safety Assessment Report/Safety Case





# COTS and NDI Software

---



- Introduction
- Related Issues
- Applications of Non-Developmental Items
- Reducing Risks
- Testing
- Summary



# **Enhanced Weapon Arming Safety By Controlled Accumulation of Arming Energy**

Thomas Harward  
Tim Bonbrake

# Problem Background

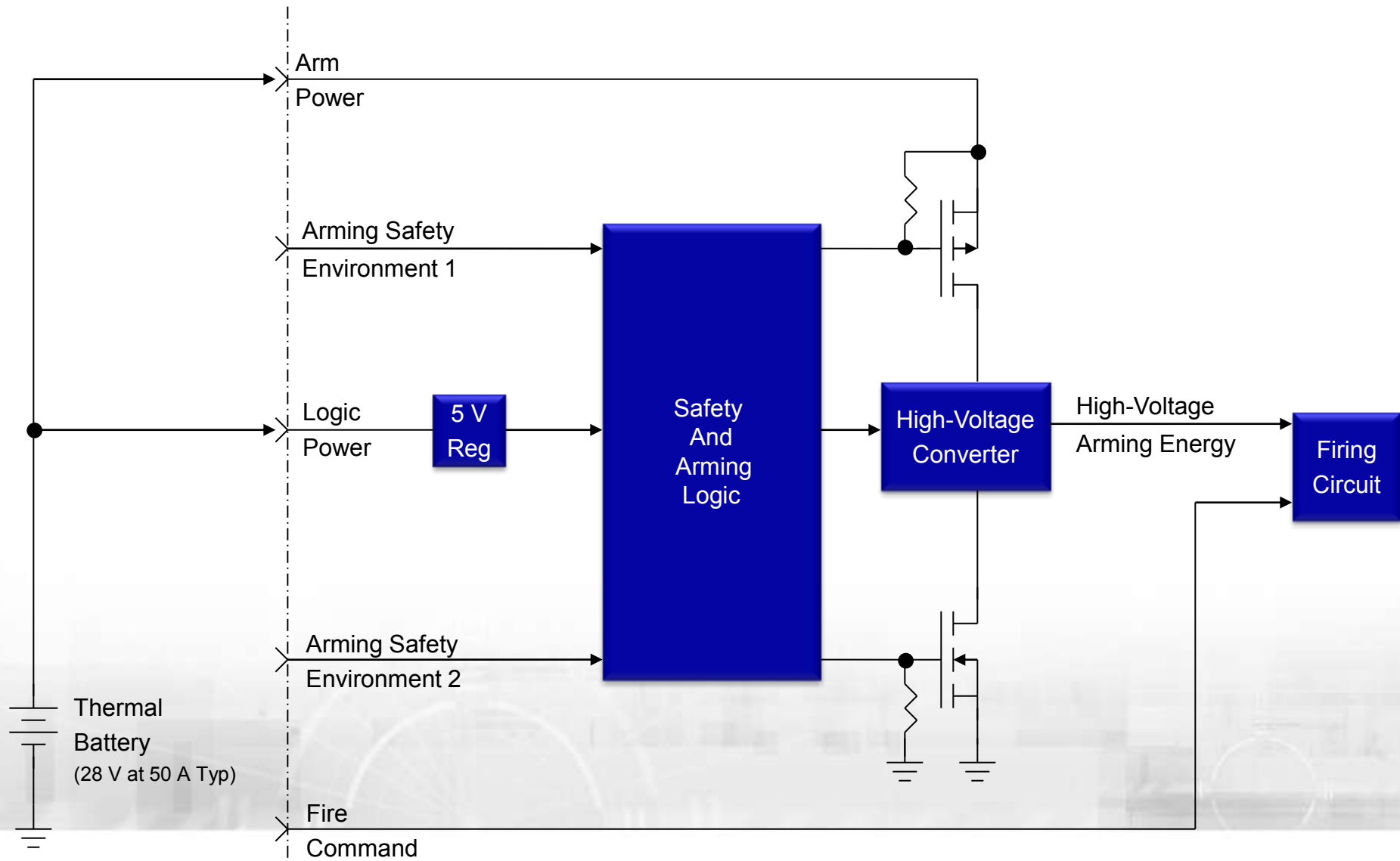
## Statement Of Technical Deficiency

---

- Weapon system electronic safety devices define arming as charging of a high voltage firing capacitor to the all-fire voltage of the initiator (approximately 1.5 kV).
- Inadvertent or early arming is defined as a safety failure in MIL-STD-1316 and MIL-STD-1901.
- Most weapon systems use medium-voltage/high-power thermal batteries to power all subsystems.
- Thermal batteries have the power capability to immediately arm a safety device in the event of a sneak circuit or failed safety feature.
- The desired approach is to slowly accumulate arming energy from the environment, for example an FZU.

# Current Weapon Arming Safety Architecture

## High-Energy Source Applied at Start of Arming Sequence



# Current Weapon Arming Safety Architecture

## Summary of Issues

---

- Requires a high-power energy source to properly operate the safety device.
- The high-power energy source may be available to the safety device prior to safe separation.
- A sneak circuit from the high energy source to the arming circuit can cause an inadvertent or early arming condition.
- In a sneak circuit condition, the arming delay would be only a few milliseconds.



# Enhanced Weapon Arming Safety Architecture

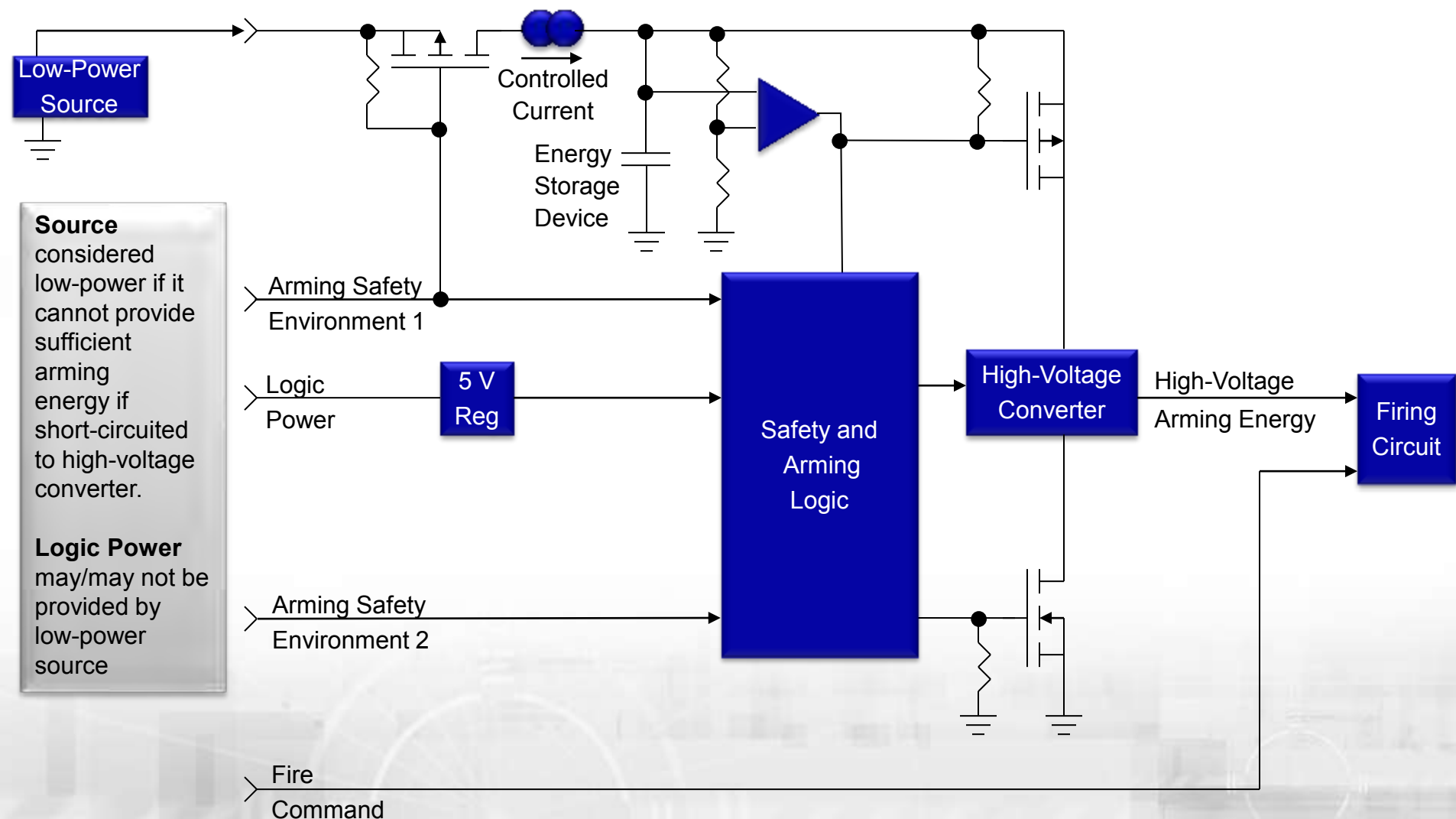
## Potential Solution

---

- Provide power to safety devices from low-voltage/low-energy power sources.
- Accumulate the required arming energy over the safe separation time based on the application.
- Store the controlled accumulation of arming energy electronically to obtain the all-fire energy at the required rate.
- Utilize this stored energy to arm the safety device when all safety conditions have been achieved and arming is commanded.

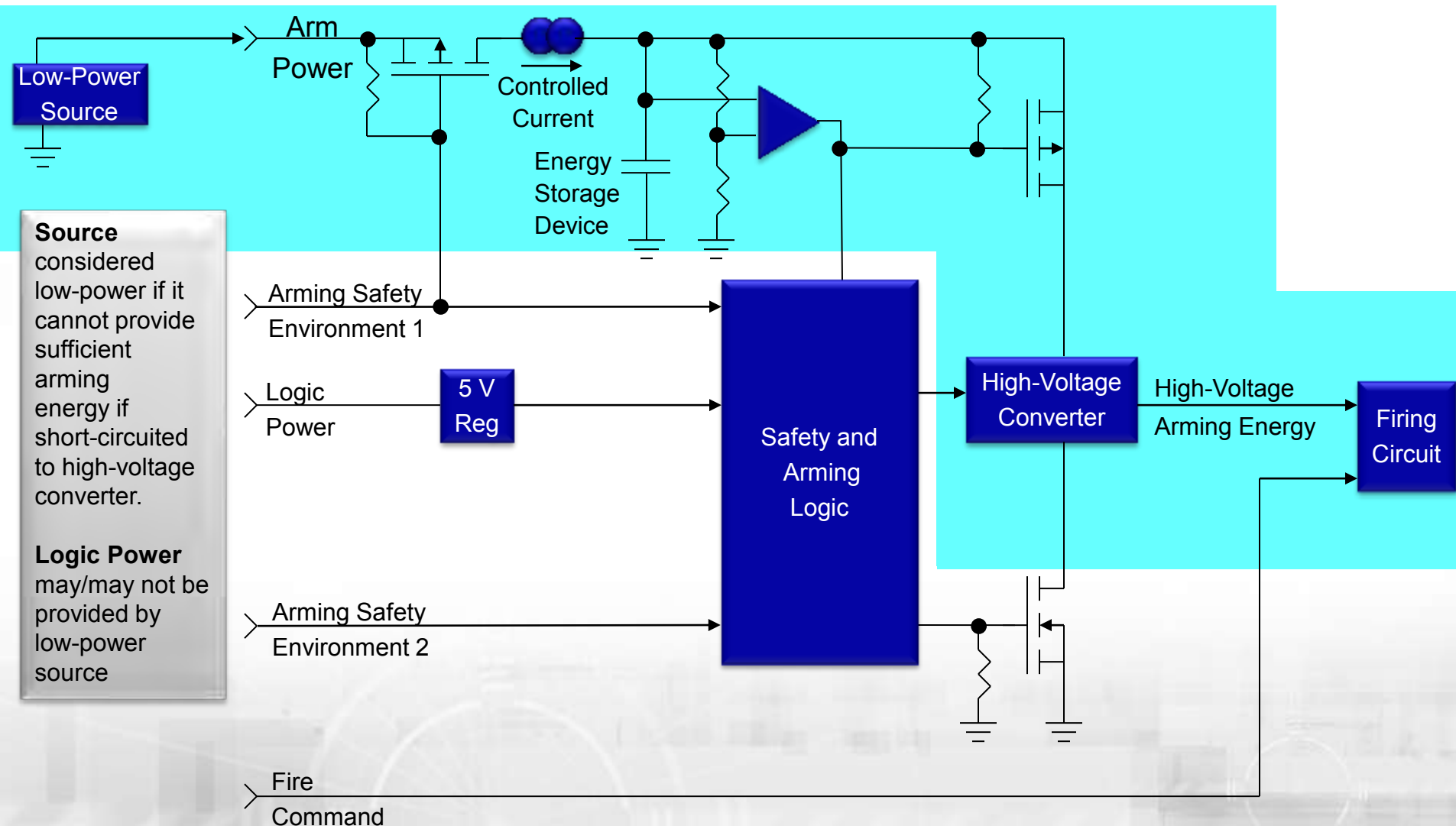
# Enhanced Weapon Arming Safety Architecture

## Controlled Accumulation Of Arming Energy



# Enhanced Weapon Arming Safety Architecture

## Controlled Accumulation Of Arming Energy



# Enhanced Weapon Arming Safety Architecture

## Controlled Accumulation of Arming Energy

---

### Advantages

- Enhanced safety with operation from a low-voltage/low-energy source.
- Sneak circuit fault tolerant due to low-voltage/low-energy source.
- Accurate control of accumulation of energy via constant current source.
- Arming energy accumulated over time precluding unintended immediate or early arming.
- Removes requirement for high-power source for weapon arming.
- Circuit cannot be armed until accumulated energy is sufficient for proper arming.



**RDECOM**

NDIA 55<sup>th</sup> Annual Fuze Conference



# Use of PLD's in Fuze Safety Critical Circuits



**TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

**Bob Hubal**

**Fuze Division, FPAT**

**METC, ARDEC**

- This paper will present my views and recent experience working with the FESWG to study the use of Programmable Logic Devices in fuzes.
- Present data gathered by the FESWG and other sources will be presented.
- ❖ *Being a fuze designer and also a member of the Army Fuze Safety Board gives me a unique viewpoint on this issue.*

- **Programmable Logic Devices (PLD) are essential tools to the fuze designer**



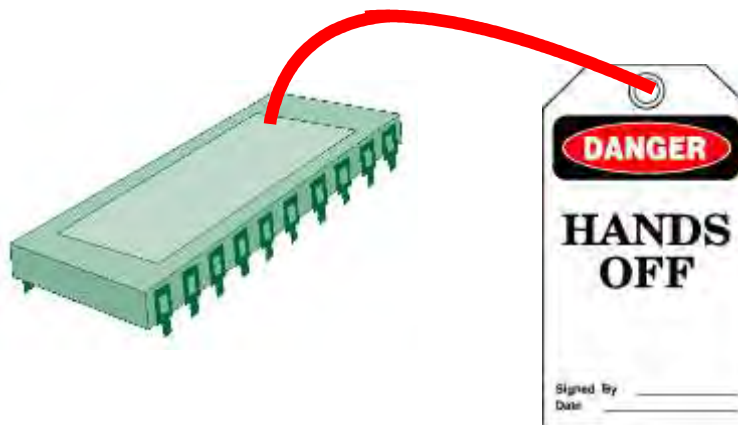
- **PLD's enable advanced fuzes to perform complex and precisely timed functions, measure environments, communicate with other subsystems, etc**
- **PLD's are used in large percentage of electronic fuzes**

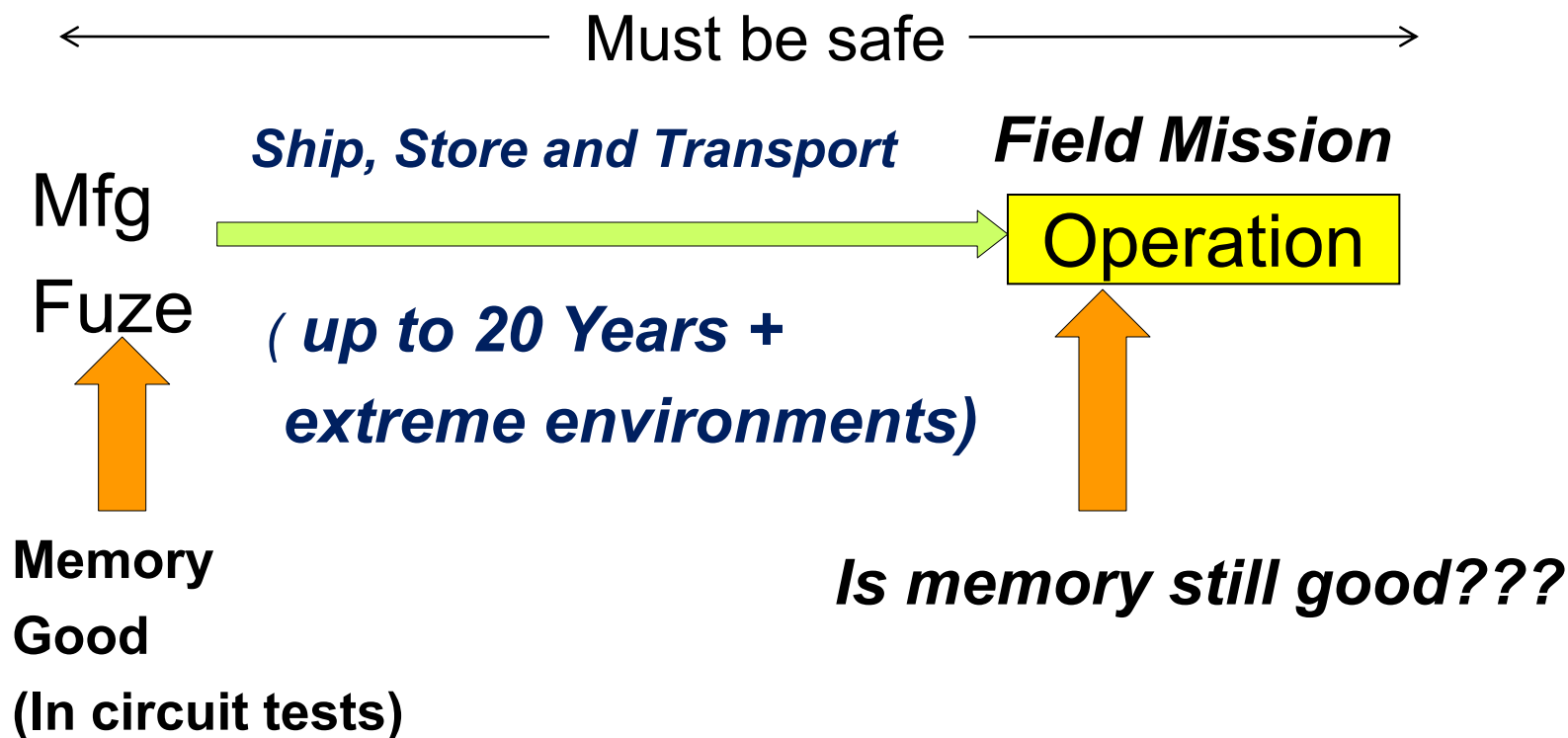


- PLD's that use charge based memory cell technology are rapidly replacing PLD's that use fixed "fusible type" memory cells
- In particular newer model PLD's which have improved performance such as reduced power consumption are only available in the charged based memory cell technology
- PLD vendors claim long memory retention time for charged based memory cells (ex: 40 years)
- Basic question for the fuze safety community – Can we rely on these devices in safety critical fuze circuits and if so what are the guidelines for their use?

- To date only fusible type FPGA's or OTP type microcontrollers have been approved by Fuze Safety Boards
- The FESWG created a subcommittee in 2009 to study the use of PLD's in fuze circuits.
  - Main question to be answered :

*“Is there an acceptable way to use PLD's that use charge based memory technology in safety critical fuze circuits?”*





- Any fuze part can fail for a number of reasons and in general fuzes are designed to stay safe if a single point failure occurs.
- However if there is an inherent memory loss failure mechanism in a PLD, a significant number of fuzes could experience failures during long term storage.
- The software code would fail randomly and the PLD's performance could become unpredictable.
- *Overall system safety would be degraded.*

- Tasked Sandia NL under the DOD/DOE TCG program to assess the validity of vendors memory retention claims
- Studied potential circuit techniques and guidelines that could mitigate the effects of PLD memory loss on safety
- Initiated an update of the FESWG Logic devices guidelines

- Sample PLD's were tested by Sandia NL's in an attempt to verify vendors memory retention claims
- Two flash microcontrollers and an FPGA's were selected for test
- The following tests were conducted:
  - Unpowered HAST/130C
  - Temperature Cycling@-55 to +150C
  - High Temp Storage @ 150C

# Summary of Data Retention Test Results

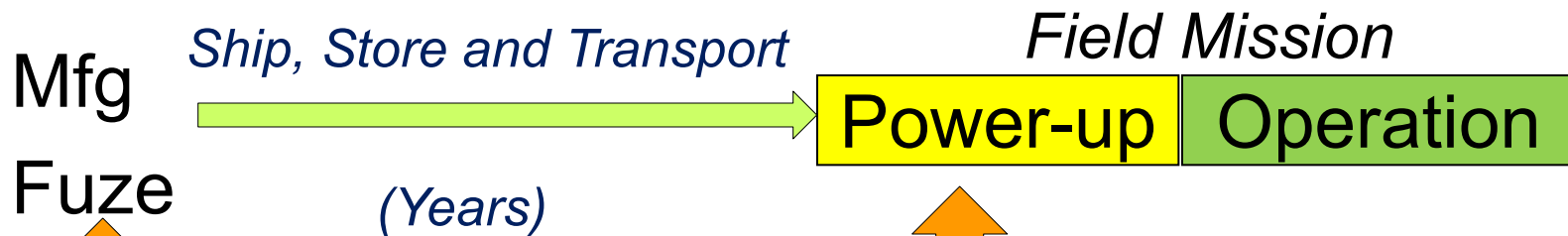


	HAST unpowered	Temp Cycling -55/+150C	Data Retention
FPGA	2 wire bond failures in 300- 400 hrs	0 Failures 1500/2000 cycles	0 failures 3000 hrs@150C
Micro 1	0 failures in 350 hrs	0 failures 1000/1500 cycles	0 failures 3000 hrs@150C
Micro 2	N/A	N/A	0 failures 8000 hrs@150C

*No memory cell failures!*







↑

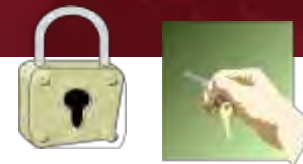
Memory  
Good  
(In circuit tests)

↑

Is memory still good???

If we can determine this  
here we can failsafe the  
system if the memory is  
corrupted.

# Memory Check Concept (Hubal Key)



Fuze Safety Critical  
Functions Locked in  
here.



Now what was that  
combination again??



**Mr PLD**

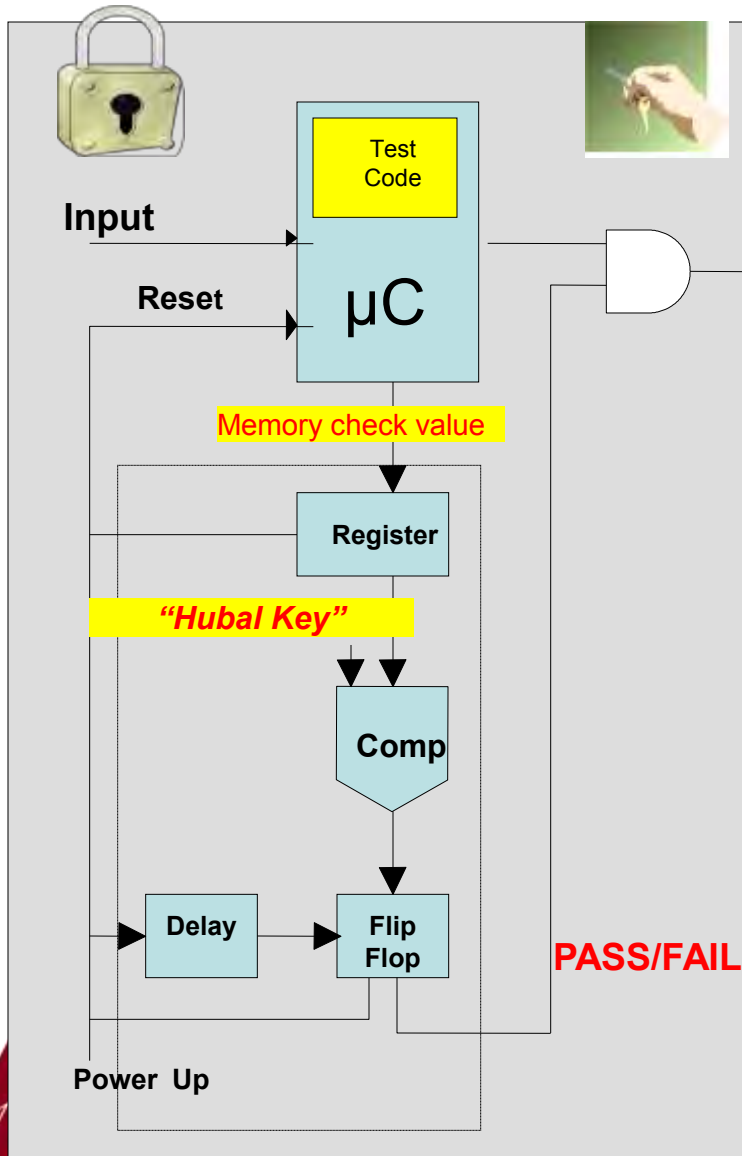
1 1 0 0 1 0 1 1 0 0 1 1 0 0 1

PLD has to derive the right combination based on checking it's memory.

This value is not resident in memory

The memory check is robust and the value is unlikely to be generated by mistake. **TECHNOLOGY DRIVEN. WARFIGHTER FOCUSED.**

# Hubal Key Diagram



## Purpose:

Checks program memory against an external “coded word” (a.k.a. key).

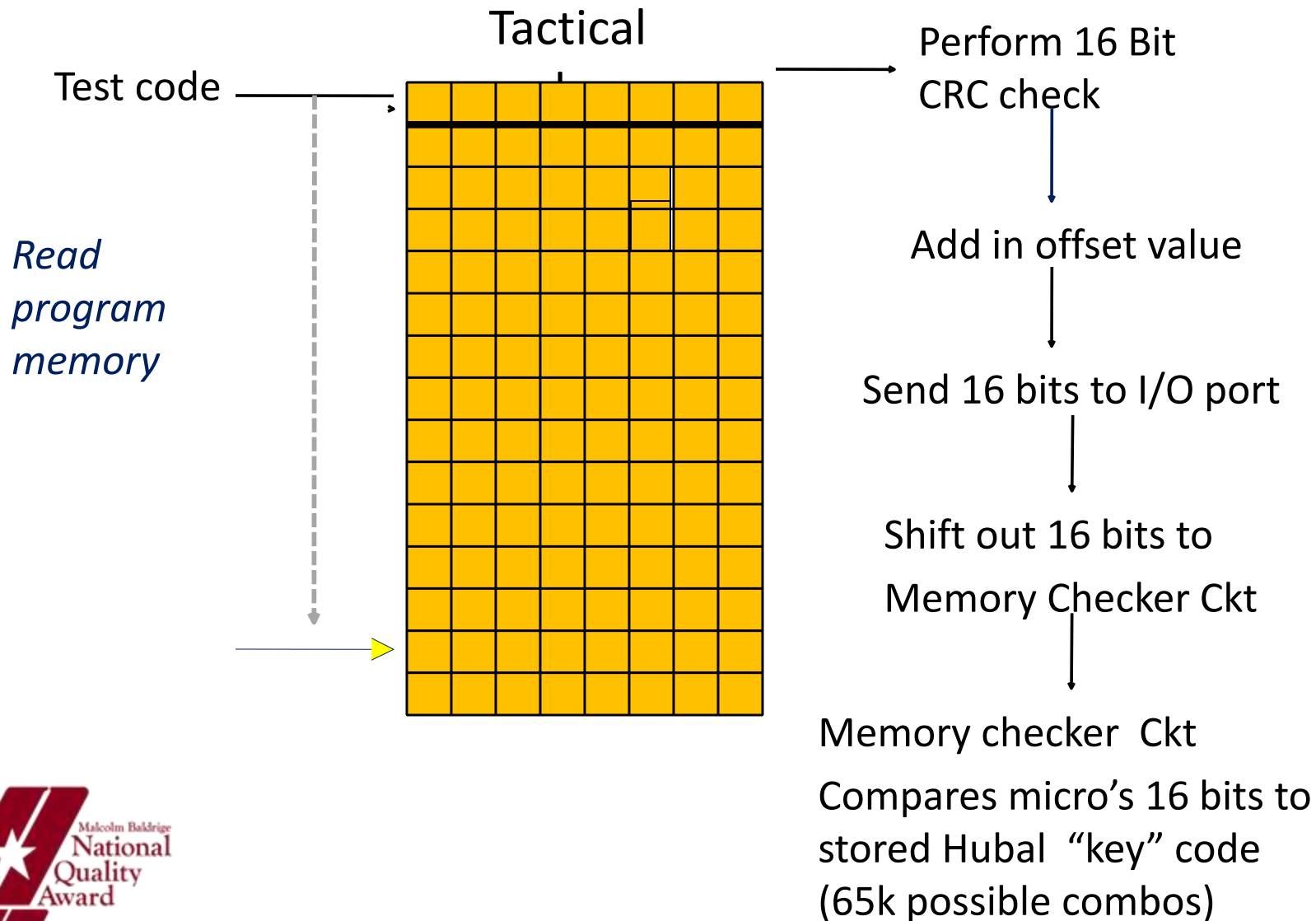
Re-programmability feature shall be defeated robustly (Service-review required).

Hubal Key acts only as a check for the integrity of EPROM/EEPROM/Flash memory.

Hubal Key does not check hardware or processing functions.

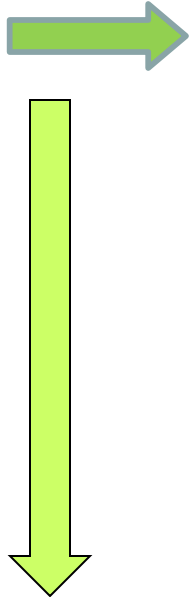
Lines between  $\mu C$  and Hubal Key are dedicated and shall not be used for any other purposes, including monitoring.

Memory integrity check shall be run upon the application of power and at the start of all arming processes.



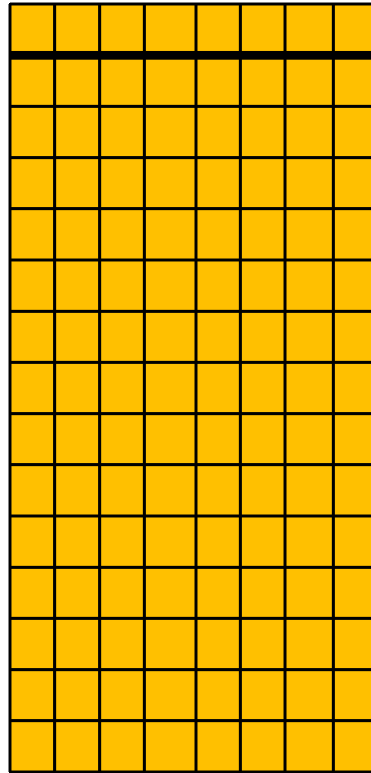


Test  
code



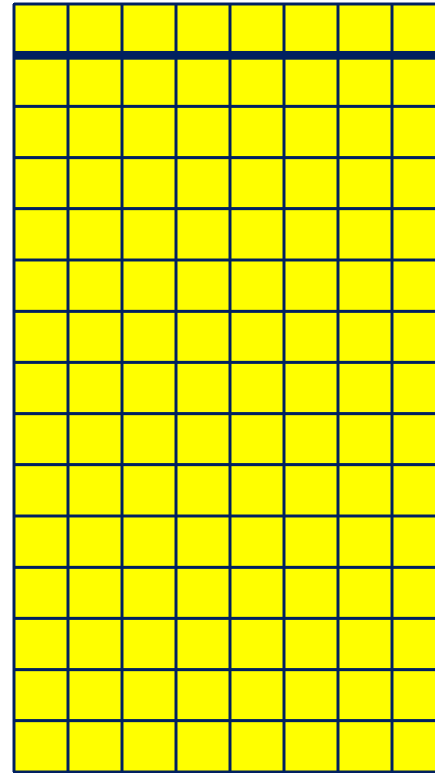
Build 16 bit code word based on results

# Tactical code



Complement of tactical code = 0

+


$$= 0$$

***Advantage : Fast – simple processing***

***Disadvantage : doubles memory size***

- Takes extra electronic parts to implement.
- More applicable to micro's, fpga's not as straightforward.
  - Can be implemented in a custom IC or by a small discrete SMD ckt
- It takes time to conduct the memory check - this may cause a problem for some systems that have to arm quickly (ex: APS & high velocity close engagement rounds).
- Memory loss still results in a fuze dud

## Example 5. Assembly Language for CRC-16 Using a Lookup Table

crc\_lo data 40h ; any direct address is okay

crc\_hi data 41h

tmp data 42h

### MAXIM APPLICATION NOTES

-----

; CRC16 subroutine.

; - accumulator is assumed to have byte to be crc'ed

; - three direct variables are used, tmp, crc\_hi and crc\_lo

; - crc\_hi and crc\_lo contain the CRC16 result

; - this CRC16 algorithm uses a table lookup

-----

crc16:

xrl a, crc\_lo ; create index into tables

mov tmp, a ; save index

push dph ; save dptr

push dpl ;

mov dptr, #crc16\_tablo ; low part of table address

movc a, @a+dptr ; get low byte

xrl a, crc\_hi ;

mov crc\_lo, a ; save of low result

mov dptr, #crc16\_tabhi ; high part of table address

mov a, tmp ; index

movc a, @a+dptr ;

mov crc\_hi, a ; save high result

pop dpl ; restore pointer

pop dph ;

ret ; all done with calculation



Sample computation time calc.  
for 16 bit crc check:

Assumptions

**4 Mhz clock** (typ internal  
clock freq. )

4 clock cycles /instruction –  
typ for Microchip parts

**4k of tactical code**

15 instructions for 2 bytes of  
memory check

1 usec per intruction x 15  
instructions x 4k/2 =

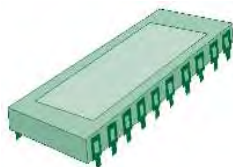
**30 msec +**

*Note: A lookup table with crc  
values must be stored in memory  
for this program*



- SOPM ESAD Safety Architectures makes use of a charged based device due to size constraints.
- Implementing CRC 16 verification of stored memory
  - Charged based device interfaces with dedicated discrete circuitry via two pins.
  - Compares expected hardwired known CRC bit-by-bit against device's memory.
  - Check occurs first, at power up.
  - Power shut down of the device occurs if:
    - Mis-match occurs
    - More than 16 bits are clocked out
    - Less than 16 bits are clocked in fixed time frame
- Active components includes a combination of shift registers, counters, and timers.
- Minimal board real estate impact.
  - Projected to be not more than 260 mm<sup>2</sup> or 0.4 in<sup>2</sup> of layout space.

- The FESWG Logic Devices tech manual has been updated to address use of charged based PLD's and include memory checking
  - Looking for feedback from the fuze industry
- More study of PLD's needed
  - Additional memory retention tests to increase confidence level
  - Develop an understanding of failure mechanisms and possible screening techniques
- Almost certainly new technologies will emerge that the fuze safety community will have to deal with



*Today*  
*PLD's*

*Tomorrow*

*???*



# **55<sup>th</sup> Annual NDIA Fuze Conference**

## **May 25th, 2011**



# **Evolving Requirements for the Use of Logic Devices in the Implementation of Safety Features**

**or**

## **An Update to the DoD Fuze Engineering Standardization Working Group's (FESWG) Technical Manual for the use of Logic Devices in Safety Features**

**John D. Hughes**

**Naval Air Warfare Center, China Lake CA, 93555**

**Safe-Arm Development Branch, Code 478300D**

**[john.d.hughes@navy.mil](mailto:john.d.hughes@navy.mil)**





# Disclaimer



- While some logic devices may be viewed as better suited for safety applications, it is important to note:
  - All logic devices can be implemented in an unsafe manner.
  - There are safety issues associated with the use of any type of logic device in safety critical applications.
  - Individual technologies may require additional measures not specifically addressed here.
- This presentation does not contain all the information found within the FESWG Tech Manual
- Presenter does not speak for the Safety Boards. Consult your Safety Authority for current requirements.



# 08 March 2011 Supersedes 16 July 2007



**NEW**

FESWG Document 2007-1

**DoD FUZE ENGINEERING STANDARDIZATION  
WORKING GROUP**

TECHNICAL MANUAL FOR THE USE OF LOGIC  
DEVICES IN SAFETY FEATURES

08 March 2011

DISTRIBUTION STATEMENT A. Approved for public release; distribution is unlimited.

**OLD**

16-July-2007

**DoD FUZE ENGINEERING STANDARDIZATION  
WORKING GROUP**

TECHNICAL MANUAL FOR THE USE OF LOGIC  
DEVICES IN THE IMPLEMENTATION OF SAFETY  
FEATURES

16 July 2007

Page 1 of 8



# Scope



- Increased use of logic devices in safety features has highlighted the need to address safety requirements in more detail.
- Document is intended to clarify the requirements of the current standards (MIL-STD-1316, MIL-STD-1911, MIL-STD-1901 and STANAG-4187, STANAG-4497, STANAG-4368) as applied to Safety Features implemented with logic devices.
- Logic Devices include programmable logic devices (PLDs), complex programmable logic devices (CPLDs), field programmable gate arrays (FPGAs), application specific integrated circuits (ASICs), microcontrollers, discrete logic, etc.
- Defines Appendix A (guidelines) and B (definitions)



# Updated Requirements



- 2. **OLD ->** All logic devices used in the safety feature shall be non-reconfigurable.
- 2. **NEW ->** While fixed-in-structure devices are acceptable and preferred, to avoid degradation of a safety feature, any logic device used in the implementation of that feature:
  - a. Shall not be re-programmable.
  - b. Shall not be alterable by credible environments.
  - c. Shall not have the SF logic configuration reside on volatile memory.
  - d. Should be rated to meet or exceed the lifecycle environments of the system. Shall have engineering rationale provided and associated risk(s) for logic devices not rated to meet or exceed the lifecycle of the system.





# Updated Requirements



## 2. Cont'd

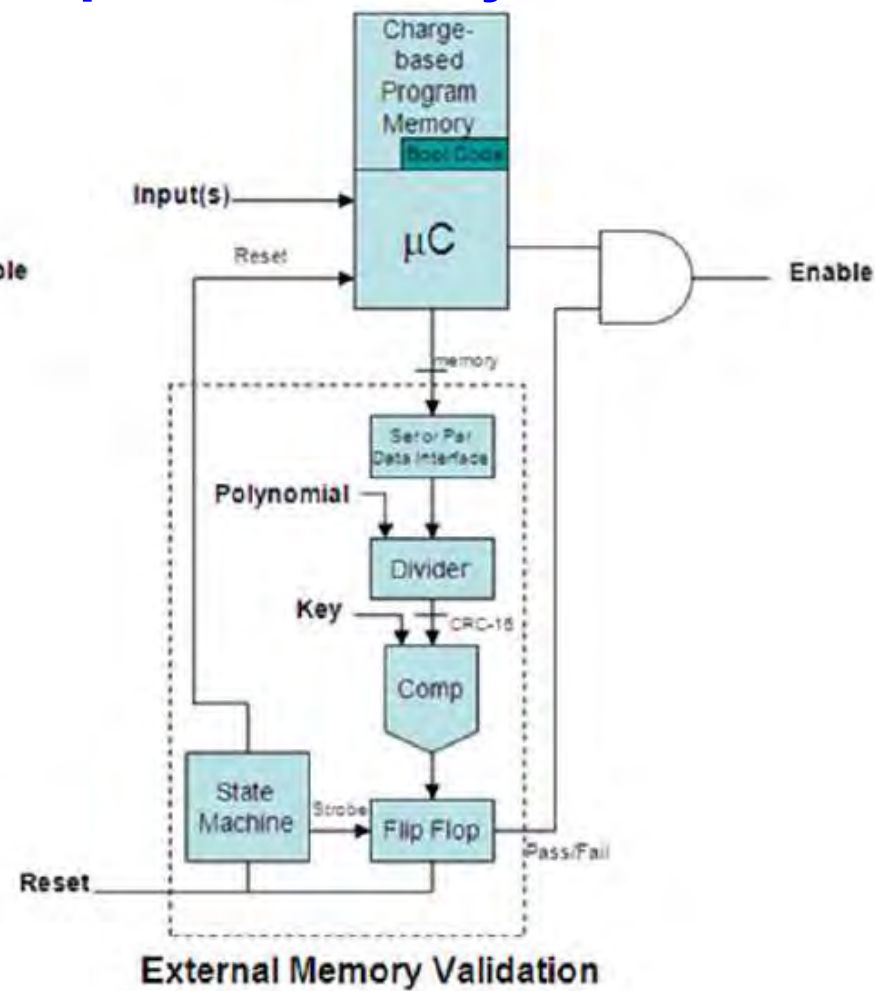
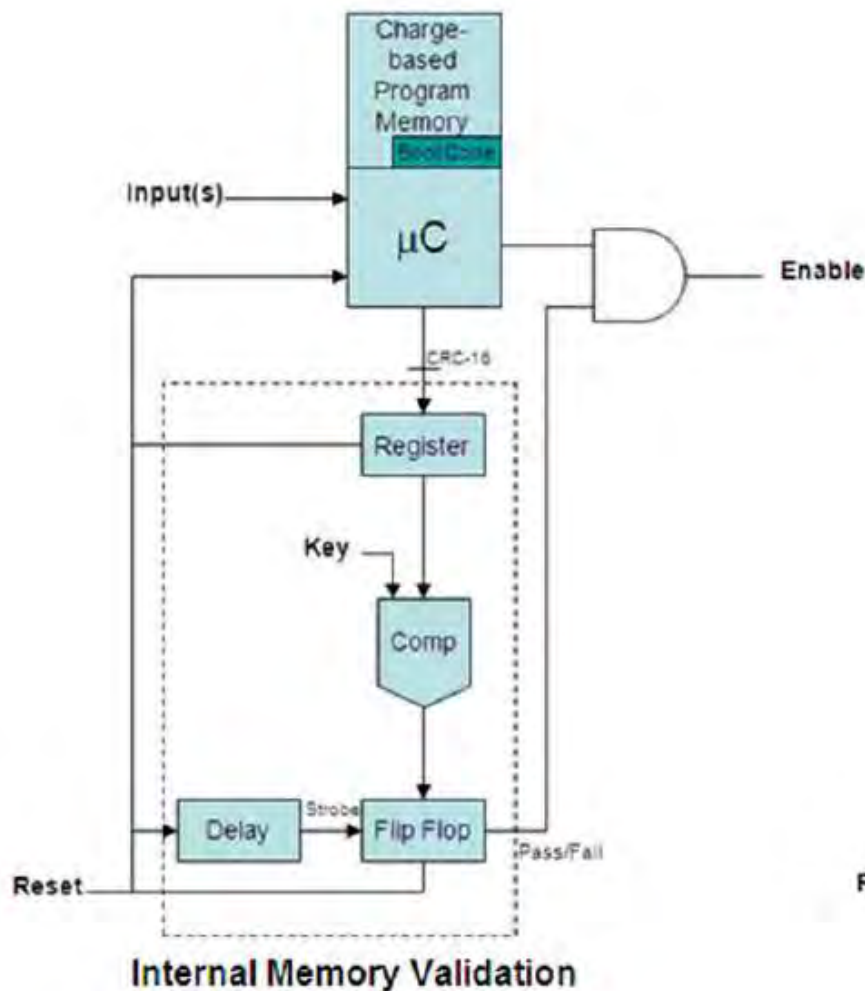
- If charged based memory is used then following shall apply:
  - Memory validation shall be performed prior to safety function
  - Validation shall have minimum rigor of CRC16
  - Computed result shall be compared externally
  - External devices shall be dedicated, fixed-in-structure, and not contain and be exclusive from any other functions.
- Consult with the appropriate Service Safety Authority for guidance.



# Updated Requirements



## 2. Cont'd - Notional example of memory validation:





# Updated Requirements



- 5. During and after exposure to power transfers, transitions, and/or transients, logic devices shall not operate in a manner that results in degradation of SF.**
- Credible power environments (brown out, surge, spikes, etc) should not cause the loss of a safety feature.
  - Logic device power supplies need to be robust.
  - **Includes reset functions [deleted reset function requirement #13 since it's covered here]**



# Updated Requirements



## Separated arming delay (new #7) from timing functions

6. Timing functions, excluding arming delay, within logic shall not be susceptible to single point or common cause failures resulting in early arming.
  - Requires independent timing with dissimilar technology or verification of the clocks with a known timed event.
7. Arming Delay single point and common cause failures shall be reduced to a minimum
  - Failures shall exist only at or near the expiration of the intended arming delay
  - Independent timers preferred
  - Shortest arm delay set in hardware should be set to the maximum practical value
  - Transmissions and validations of arm times should be robust (checksum, parity, CRC)



## Deleted Requirement



**Covered by requirement #5 so verbiage added to A.5**

**13. Reset functions shall not be susceptible to single point or common cause failures that result in unsafe states.**

- Redundant resets with different implementations.
- Logic device reset circuitry must be extremely robust.

Moved



# Requirements



1. **Each Safety Feature (SF) implemented with logic shall use the least complex logic device that can practically perform the required functionality.**
  - Minimizes the subversion of SF(s) due to unintentional and/or unrecognized modes of operation, including failure modes.
  - KISS method.
  - Complex devices require more analysis, documentation, testing and more scrutiny by the safety authority.

No Change



# Requirements



- 3. Where all SFs are implemented with logic devices, at least two SFs shall be implemented with dissimilar logic devices.**
- **Minimizes the potential for common cause failures.**
  - **Where practical, at least one SF shall be implemented with discrete component(s).**
  - **Dissimilar logic refers to distinct methods and/or materials used to develop a particular device that result in devices with minimal common cause failures. Some examples include:**
    - **Full Custom ASIC**
    - **Discrete components**
    - **M2M FPGA**
    - **OnO FPGA**
    - **Microcontroller**





# Requirements



- 4. SF logic shall be implemented in accordance with the device manufacturer's latest specifications and notes.**
- Safety critical details could be buried within data sheets and/or footnotes.**
  - Conflicts between manufacturer's specifications and other requirements shall be reviewed and approved by the safety authority.**
  - All programming functionality, testing functionality, used pins, and any other non-operational functionality shall be appropriately disabled and terminated.**



# Requirements



8. **(OLD #7)** Logic implementation shall replicate the documented design.
  - Ensures the intended design is actually implemented.
  - No optimizations or changes to an approved design.
  - Know your design tools.
9. **(OLD #8)** Where all SFs are implemented with logic devices, the SF logic shall be physically and functionally partitioned from each other.
  - Minimizes the potential for inadvertent subversion such as sneak paths or Single Event Upsets.

No Change



# Requirements



10. **(OLD #9)** All logic and/or functionality available within a device shall be disclosed, documented, and assessed in safety analyses and evaluations.
  - Undocumented functions within a SF can compromise the safety of the design and is unacceptable.
11. **(OLD #10)** SF documentation shall include the complete logic flow with all inputs and output defined, along with timing and interdependence of events.
  - Assists with design understanding and verification.



# Requirements



- 12. (OLD #11) Manufacturing documentation and processes shall ensure that logic devices within an approved design are produced with an identical configuration.**
- Assures logic devices are reproduced consistently throughout production.
- 13. (OLD #12) Development tools shall be documented and controlled via configuration management procedures.**
- Assures logic devices configuration matches the intended design.
  - Know your tools and document them.



# Requirements



**14. Power for SF logic should be partitioned from other power such as communication or platform power.**

- Minimizes subversion of a safety feature

**15. Power for SF logic should be applied as late in the launch sequence or operational deployment as practical.**

- ESAD without power = SAFE

No Change



- **A copy of the technical manual may be obtained via mail from the following:**

**Chairman**

**DOD Fuze Engineering Standardization Working Group**

**U.S. Army Armament Research, Development and  
Engineering Center**

**ATTN: RDAR-MEF-F**

**Picatinny Arsenal, NJ 07806-5000**



**Questions???**



**Comments??**





# **Universal Fuze Monitoring Test System (UFMTS)**

**55<sup>th</sup> Annual NDIA Fuze Conference**

**Jason Koonts  
NSWCDD, Computer Engineer  
(540) 284-0179  
[jason.koonts@navy.mil](mailto:jason.koonts@navy.mil)**



# Agenda

---



- Background
- System Upgrade
- Increased Functionality/Benefits
- Summary

# What is the UFMTS?

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- Universal Fuze Monitoring Test System (UFMTS)
- Hardware and software suite
  - Agilent VEE Graphical Programming Language
  - Various instruments
    - Oscilloscope, Spectrum Analyzer, Power Supplies, etc.
  - Custom hardware
    - Interface to various fuzes
    - Junction Box
- Allows for testing Navy NATO standard fuzes in one comprehensive system
- Main application is ordnance assessment

# Project History

- Initial purpose of hardware was to serve as MK419 Multi-Function Fuze (MFF) tester at NSWC Crane
- Crane utilized hardware to turn system into MK432 fuze tester
- Dahlgren was provided funding independently to develop test set for MK437 Multi-Option Fuze for Navy (MOFN) in FY05
  - Decided to leverage Crane's MK432 tester to have one hardware suite capable of testing both fuzes
- Hardware shipped to Dahlgren for full integration of MOFN into software suite
  - MK432 testing not perfected
- New MFF production lot being built and no current testing capability at Dahlgren
  - Funding provided to incorporate MFF capability into MK437 and MK432 test set in FY09 (creates UFMTS)
- Design from an Ordnance Assessment (OA) perspective
  - Speed and efficiency
  - Minimal operator interference

# Legacy System

- Fuze setting station and testing station
  - Very slow to set and then test each fuze
  - Separate desktop PCs for setting the fuze and running the tests
  - Two computers used increases complexity
- Code not designed for Ordnance Assessment
  - Poor operator interaction and data reporting
- Very buggy code!



# Upgraded System

- Design and code the system for an OA application
  - Minimal operator interaction
  - Fast testing algorithms
  - Efficient, clean data reporting
- Hardware modifications
  - Remove or replace obsolete components
  - Evaluate all devices in the system
  - RF range simulator upgrade



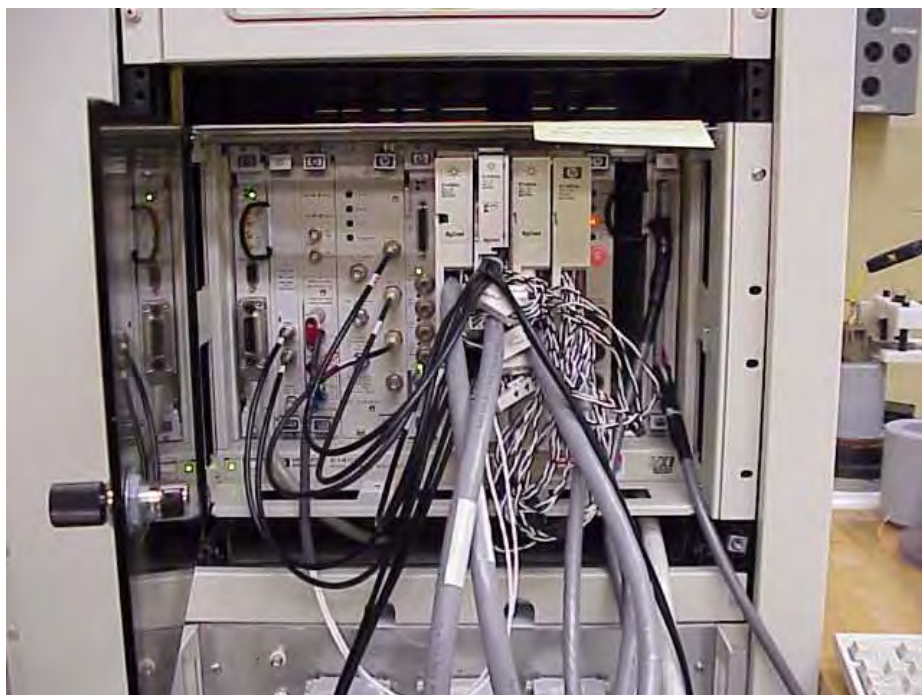
# RF Range Simulator Upgrade



- RF Range Simulator (RFRS) incorporated into test system
  - Built by Electronic Development Corporation
  - Allows for proximity mode and RF testing
  - Simulates surface and air encounters
- EDC offered significant hardware and software changes to increase functionality of the instrument



# Hardware Changes

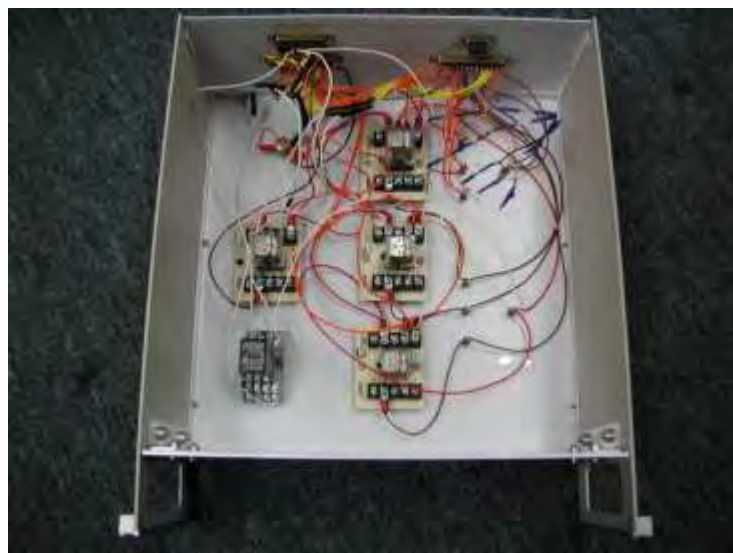


**Original Wiring**

**Neat and Tidy**



# Original Custom Boxes



**Interface Box**



**Junction Box**

# Junction Box

- J-Box
  - 2U unit (could easily have been 1U)
    - Could take up much less room, smallest box we could find
  - Performs all necessary switching to connect test points from all three fuzes to all of the instrumentation
  - Provides spin switch closure for time zero of MK432, level shifting for MK419, crush switch emulation for PD functionality of MK419 and MK437, and multiple det resistances for minimum and maximum spec values across all three fuzes





# Instrumentation

- Using one computer for fuze setting and the test program
- Shrank system from two full side by side racks to one rack with room to spare
- Added a counter to increase functionality
  - Necessary for MOFN testing
- Removed and replaced obsolete components
  - i.e. VXI Oscilloscope card was broken
- Only need two Relay Matrix Switches and one Relay Driver Module
  - Down from 4 relay matrix switches and two relay drivers
- Large instrumentation set to allow for future capability
  - Relay matrix switch has open channels
  - Fuze interface cable is not utilizing all pins

# Fuze Connection and Interface

- One shared cable using military connectors for reliability and ruggedness
- Interfaces designed in house
  - Minimal time required for swapping fuzes
  - Cores easily interchanged to switch among the three fuzes
- Modular interface design is vast improvement over original approach





**MK432**



**MK437**



**MK419**

- One comprehensive instrumentation and software set capable of setting and testing all Navy NATO standard Electronically settable fuzes
- MFF Test time decreased from ~6 minutes to 90 seconds
  - Working with contractor to realize part of this time savings on their tester

# In Summary

---

- Original system only capable of testing MK432
  - Outdated hardware and software requiring work
- Requirements analysis to trim system and remove unnecessary, broken, or obsolete hardware
- Custom PCB designed to allow switching among and testing three Navy electronically settable fuzes
  - MK432, MK437, MK419
- RFRS upgrade increased functionality for proximity and RF testing
- Ability to expand for addition of new hardware and fuzes to be tested



# Questions?



Distribution Statement A – Approved for Public Release; Distribution is unlimited

**Pyro-MEMS ®**  
**Technological breakthrough in fuze domain**

-----  
**Fuze Conference 2011**

**Renaud Lafont**

**Salt Lake City, UT**

**24<sup>th</sup> of May 2011**

## **Content**

- 1. NEXTER Munitions Fuze activities**
- 2. Design & Demonstration of 25mm Airburst ammunition Mk I**
- 3. Design & Demonstration of 40mm Airburst Fuze Mk I**
- 4. Pyro-MEMS ® for ammunition Mk II**

# **1. NEXTER Munitions Fuze activities**

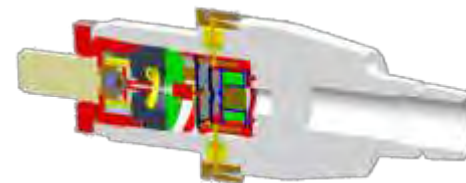
## NMu: Fuzing System manufacturer

**Products:** Fuzing system & SAU for missile, tank ammunition (120, 100, 90 mm caliber), naval artillery (100mm caliber) and medium caliber (40, 30 and 25 mm caliber).



### Strengthes:

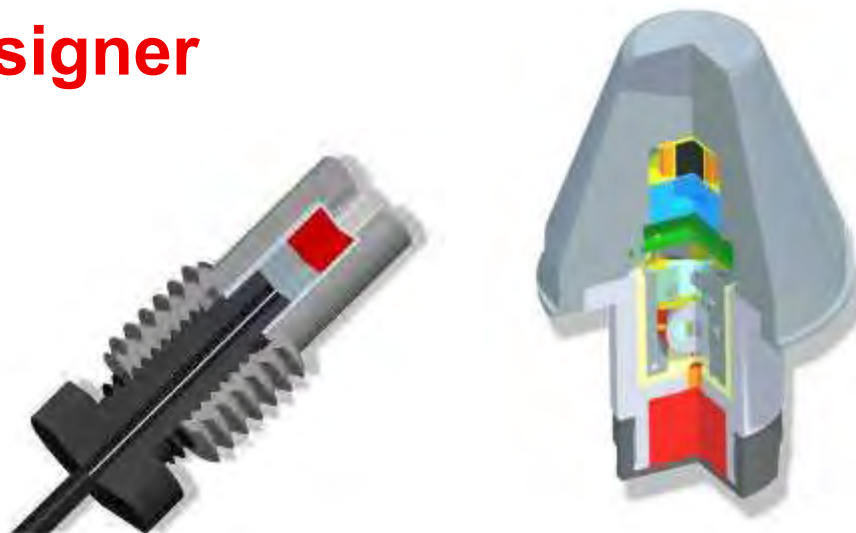
- ▶ Pyrotechnical components manufacturer (primary & secondary explosive)
- ▶ Own proving ground, recovery system and data recorder
- ▶ Designer of the complete munition



## NMu: Fuzing System designer

### Applications:

- ▶ Airbursting ammunition
- ▶ Opto-Pyro
- ▶ Low Energy EFI
- ▶ Pyro-MEMS
- ▶ Course Correction fuze (cooperation with JUNGHANS Microtec)



### Strengthes:

- ▶ Modelisation
- ▶ Data recorder
- ▶ Own proving ground (static, pyrotechnics, dynamic)
- ▶ Same group than weapon system designer (NEXTER Systems)



# **1. Design & Demonstration of 25mm Airburst ammunition-Mk I**

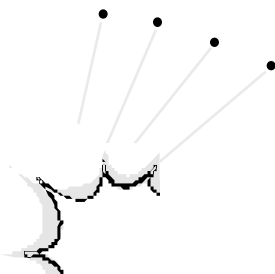
Contract n°05.50.208 – Improvements of medium  
calibre ammunition



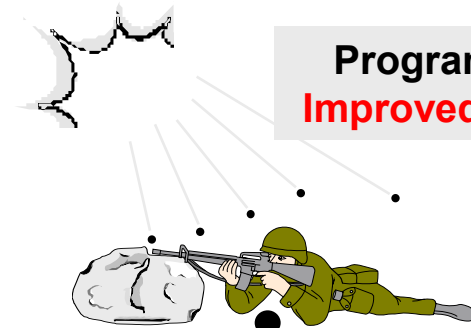


## Aims of the study

- ▶ Airburst has to be initiated above the target with an accuracy of 1 m at 1000 m
- ▶ Airburst mode shall be compliant with the maximal range of the 25, 30 and 40 mm weapons
- ▶ Impact mode available
- ▶ Compliance with STANAG 4187
- ▶ Airburst Fuze Programming Unit shall be able to equip existing weapons systems (upgrading)



**Traditional PD**  
**Reduced efficiency**



**Programmed AB**  
**Improved efficiency**

# 25 HEI AB Mk I

nexTER  
MUNITIONS



## ► Programming Unit

- Inductive coil (Mode + Chronometry)
- Impact mode remains available without programming unit

## ► Operational modes

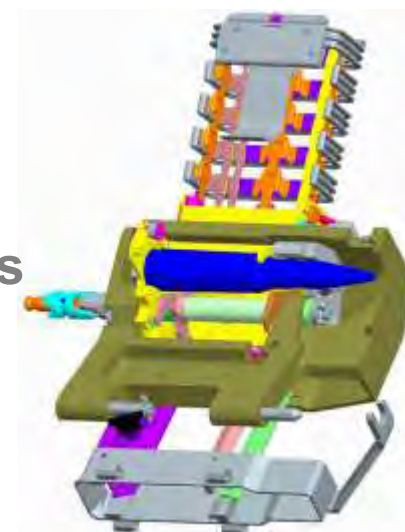
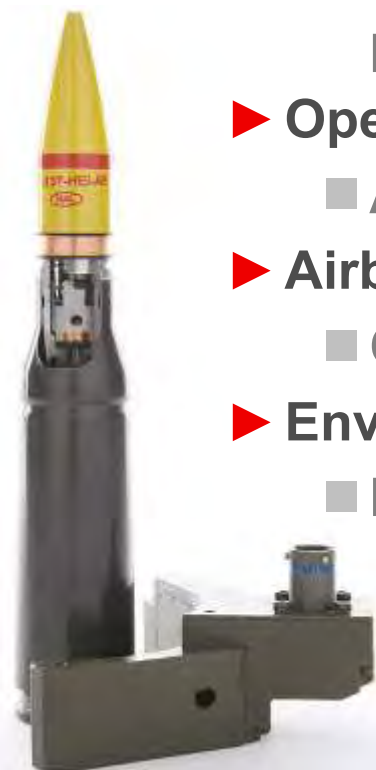
- Airburst +PD +Self-destruct

## ► Airburst performances

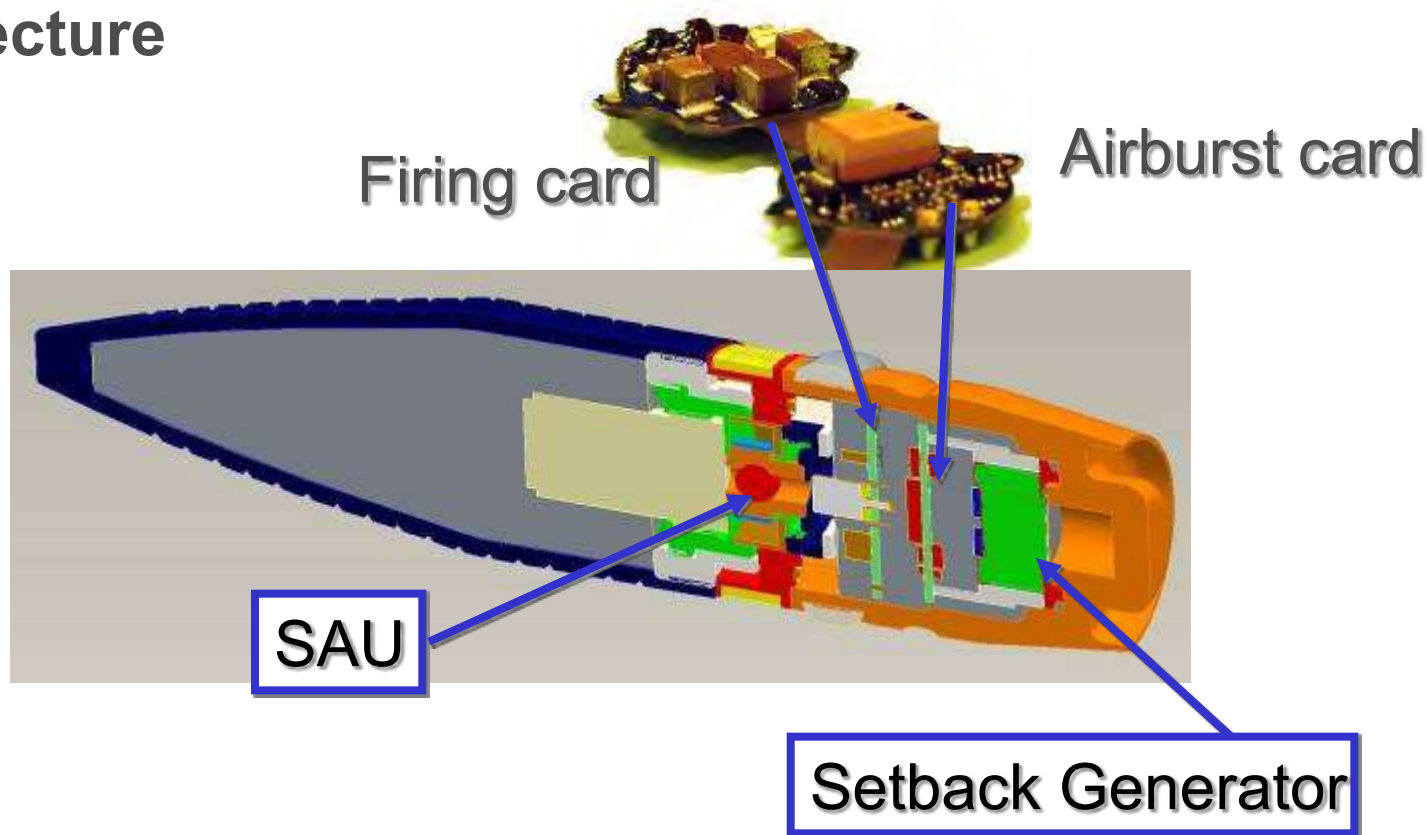
- Chronometry :  $\pm 0.5\text{ms}$

## ► Environment conditions :

- Medium calibre 25x137 : 100 000 g 1000rd/s



## ► Architecture



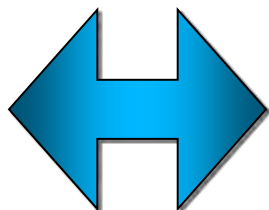
Electronics and SAU designs are deeply fitted into each other during engineering process.

## ► Architecture

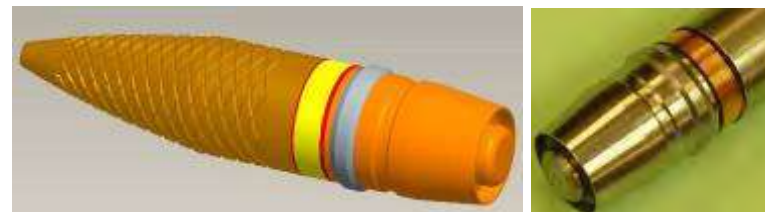


HEIT

Same shape + Same mass  
=Equivalent ballistics



HEI-AB



## Programming coil

- Induction programming
- The ammunition are programmed before entering in gun chamber
- Programming time about 65ms
- Weapon cycle: 150ms (firing rate 400 rds/mn)



*Programming Head*

## ► Firing evaluation

Airburst mode

-single shot

-Burst

Functioning @ 100m



Impact mode (spotting charge)

Functioning @ 100m



# 1. Demonstration and development of Nexter 40CTA Airburst sub-system -Mk I



## Nexter 40CTA Airburst sub-system

### ► Nexter Munitions proposal

#### ■ A two stages fuze :

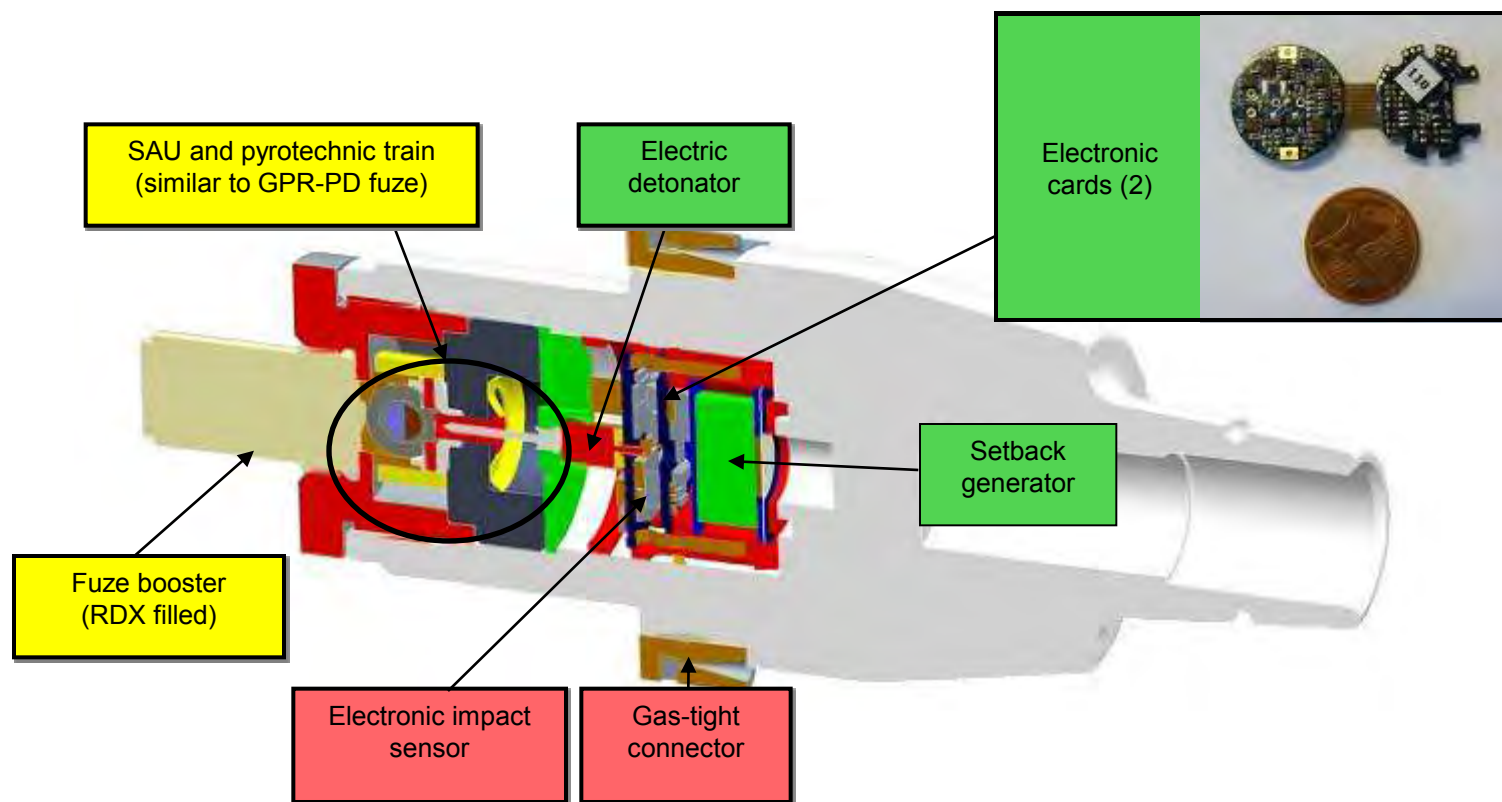
- Mechanical SAU : low risk design validated with 30x150 Rafale and GPR-PD ammunition fuze for safety and STANAG 4187 compliance,
- Electronic unit with :
  - Two electronic boards including Airburst, Point Detonating, Self Destruction functions,
  - A setback generator integrated in the fuze : electrical energy on-board generation for the pyrotechnic train electric initiator

#### ■ A fuze setter :

- Compact and tunable design compliant with the weapon mechanical interfaces and current cartridge programming coil



## Nexter Munitions 40CTA Airburst Fuze



## Nexter 40CTA Airburst Fuze (1)

Main features :

- ▶ **Three modes fuze, electronically driven**
  - Impact mode delay,
  - Impact mode quick
  - Airburst mode
- ▶ **Safety (mechanically driven, compliant with Stanag)**
  - Storage
  - Handling
  - Firing phase
  - Muzzle safety
- ▶ **Self-destruction time, two options**

## Nexter 40CTA Airburst Fuze (2)

Main features :

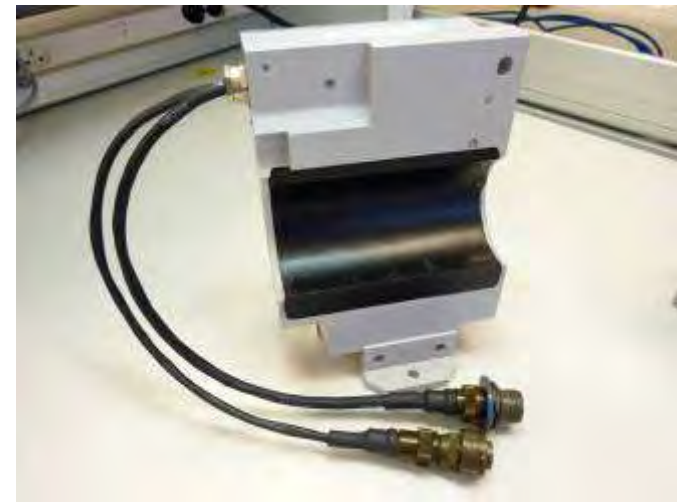
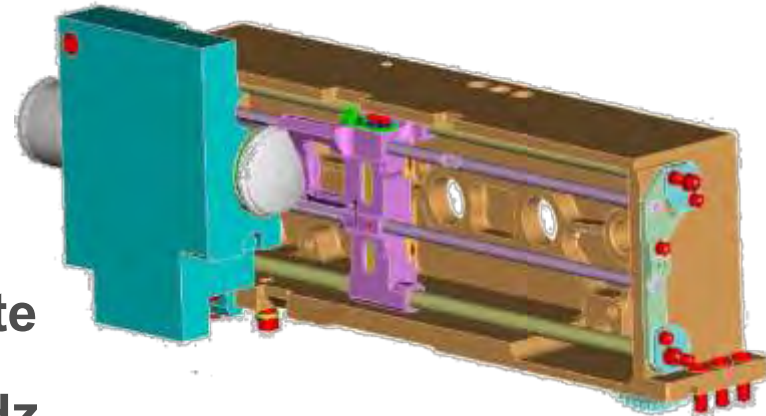
### ► Safety

- If fizzle occurs, there is no on-board energy after 10 s : ammunition is then totally safe for handling ,
- Self-destruction is independent of programming,
- The energy for pyrotechnic train is given by setback generator : the low level of energy transmitted by Fuze Setter is not compliant with electric detonator initiation,
- Default mode : point detonating (if no signal transferred or false programming message),
- No functioning of the fuze against thin aluminium plate

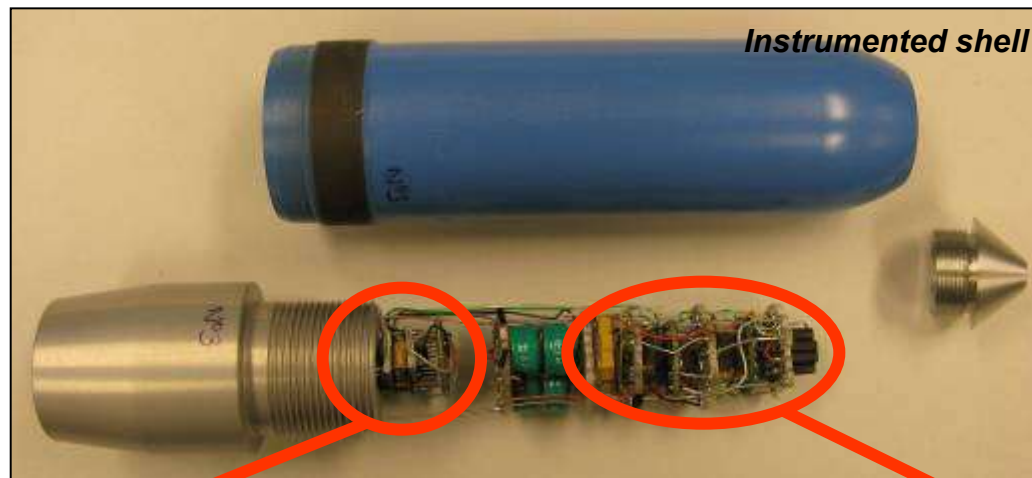
## Nexter 40CTA Airburst Fuze setter

Main features :

- ▶ Magnetic head
- ▶ Programming phase duration compliant with maximal firing rate
- ▶ Programming frequency : 100 kHz
- ▶ Firing in CTA Weapon with FS : more than 400 firings

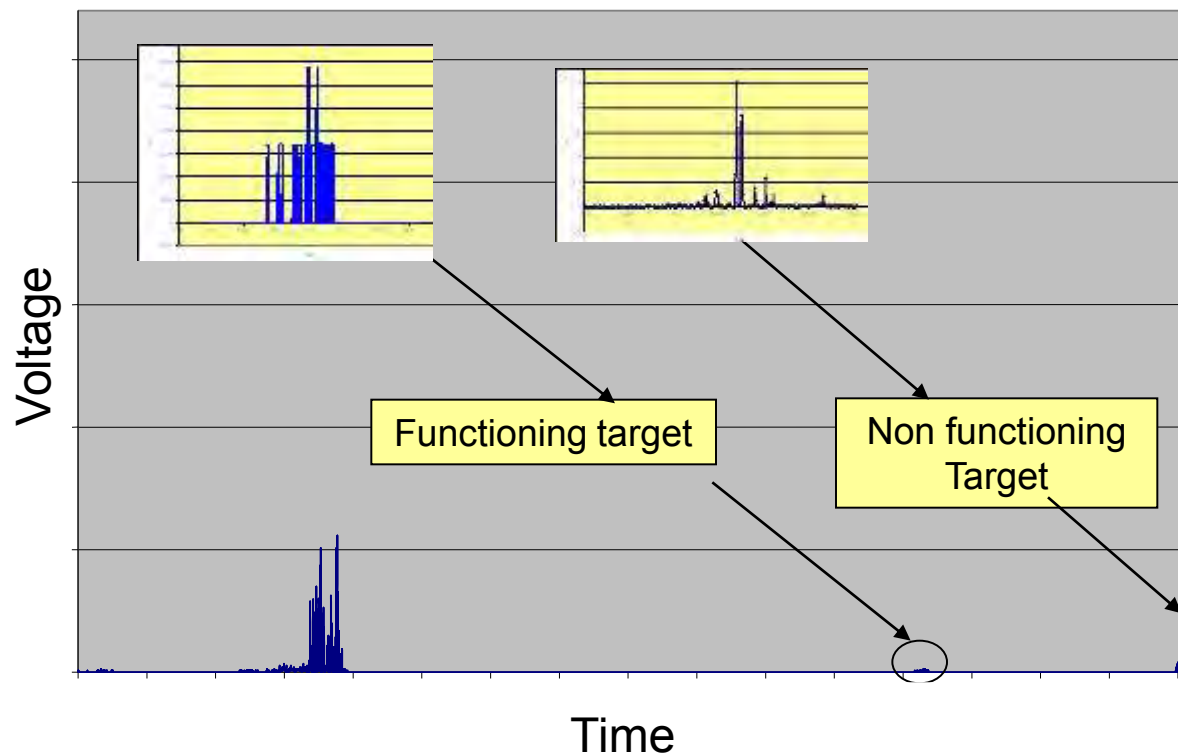


# Embedded Instrumentation



# Impact Detection

Obus 3 / Détection impact



## Analysis :

- ▶ Very high sensibility of the detector
- ▶ Detection of a target with thin aluminium plate  
Détecteur
- ▶ Detection of the specified target
- ▶ Tested successfully on others targets types

# Pyrotechnic fire train

## Normal fonctionning :

- ▶ **Transmission : 16 functioning on 16 trials**

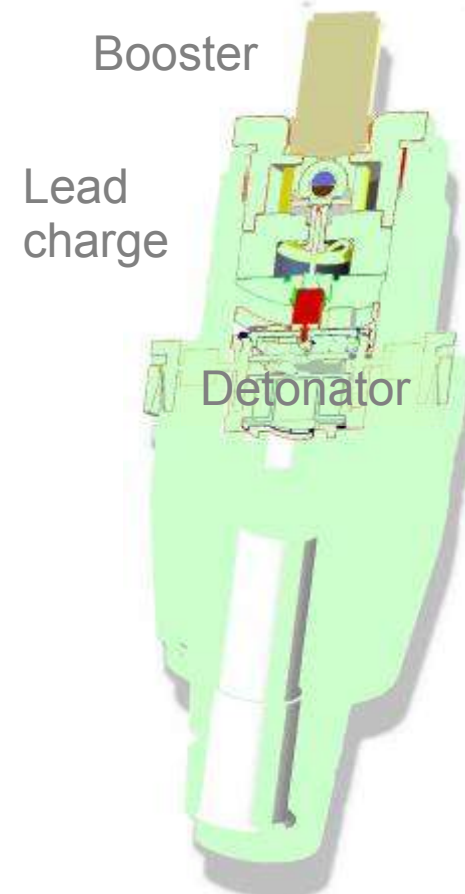
## Hardened tests:

- ▶ **Transmission :**

- Temperature tests (-46°C et +63°C)
- Hardened factor : filling of the detonator.

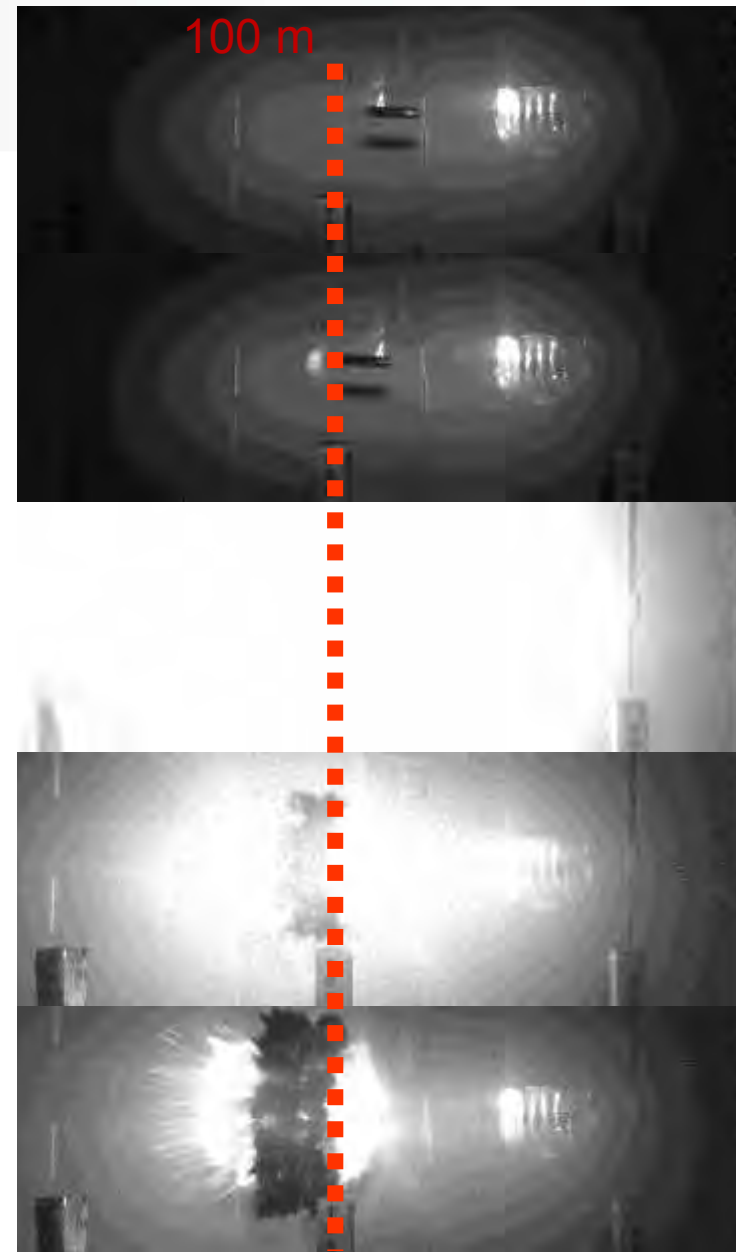
- ▶ **No-transmission:**

- Temperature tests(-46°C et +71°C),
- Hardened factor : increase of booster sensibility.

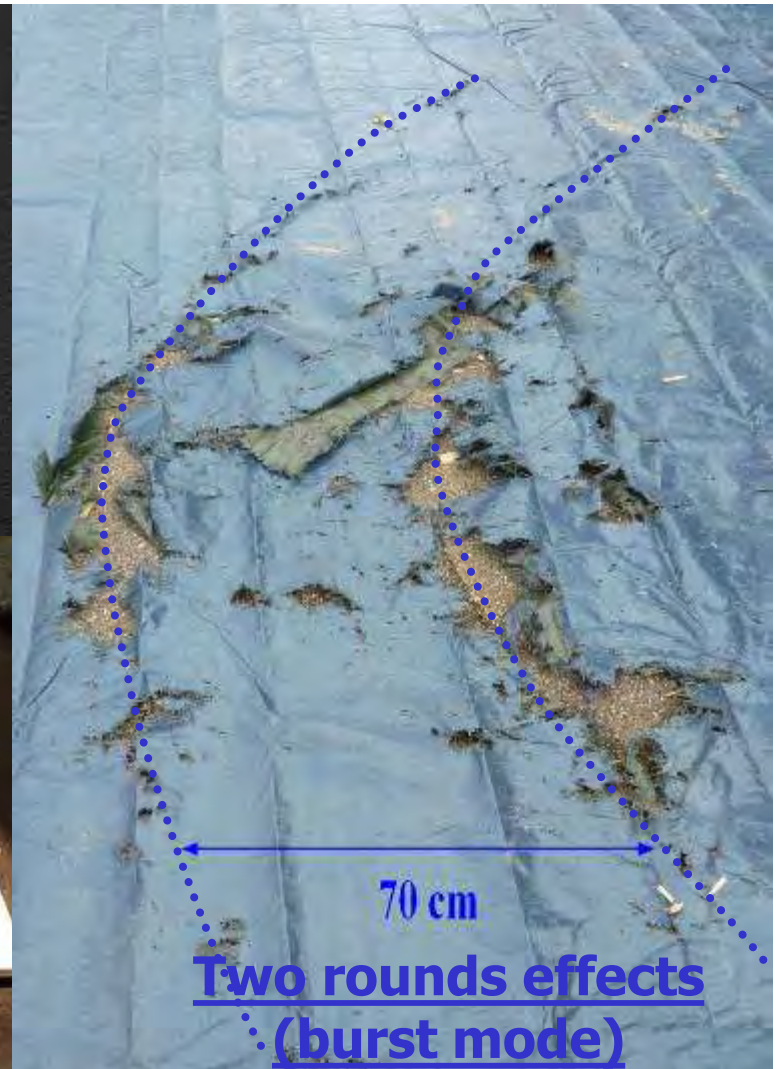




# Airburst accuracy



# Airburst accuracy



# Warhead effects

AIRBURST

FASTCAM-APX RS ...  
8400 i/s  
1/30000 sec  
1024 x 368  
image : -10398  
-00:00:01.237857sec  
NEXTER Munitions

Impact double brick-wall impact



# 1. Pyro-MEMS®

- **Preliminary study of  $\mu$ SAU**
- System level test: Warhead functioning demonstration
- Preliminary study of medium caliber MEMS based SAU



# Contract 03.04.078 – Demonstration of miniaturized SAU



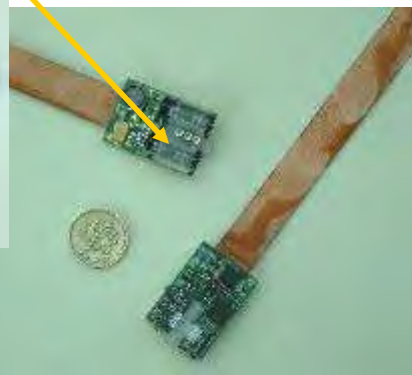
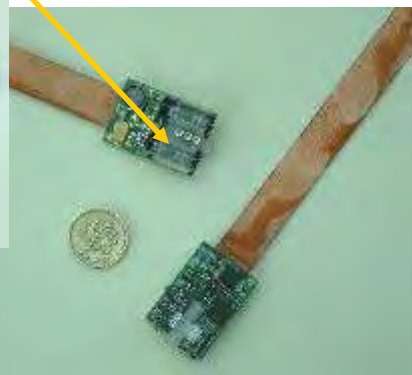
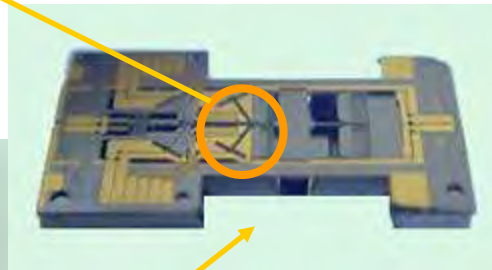
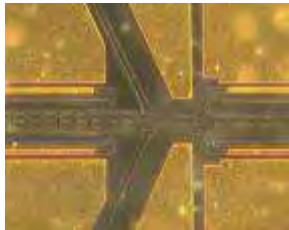
## The Step Forward

03/2007 – delivery of 10  $\mu$ -SAU

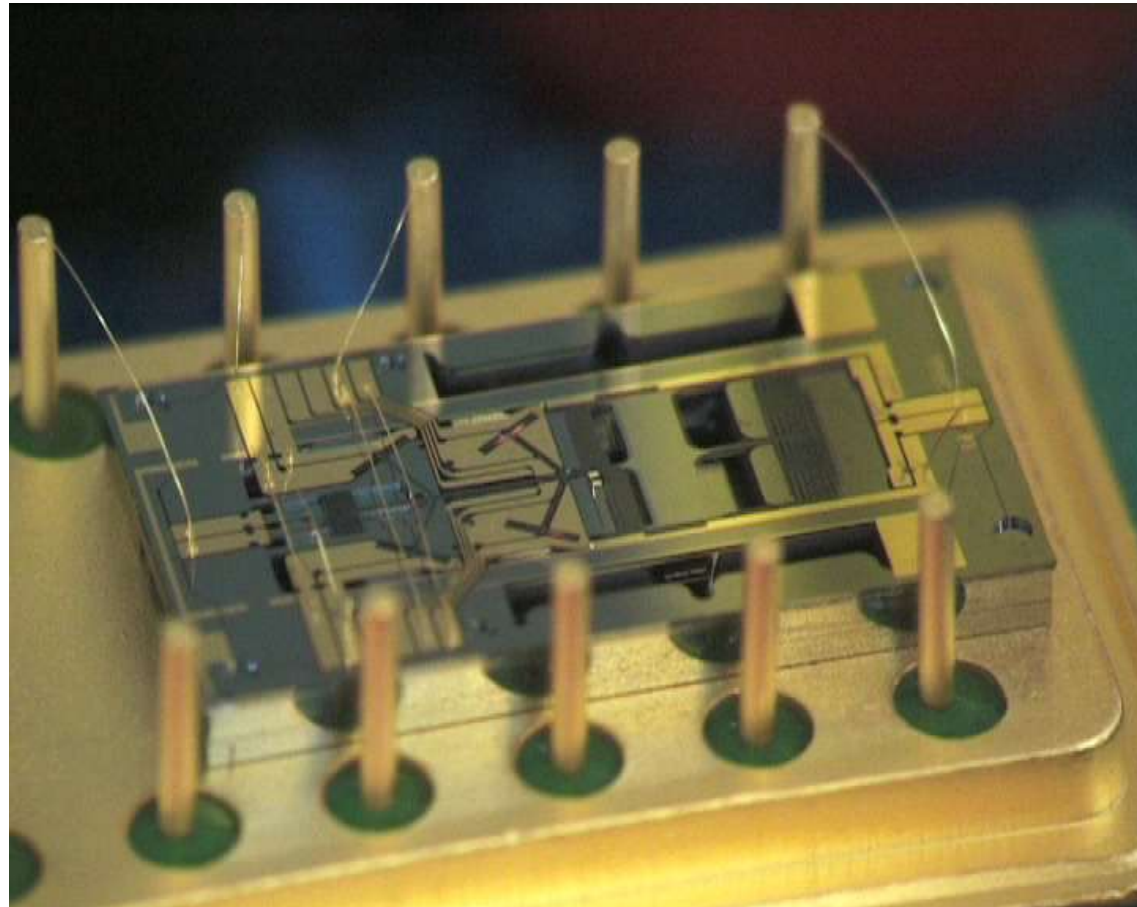
## Requirement

- ✦ Pyrotechnical safety managed by electronically controlled MEMS
- ✦ Volume less than 2 cm<sup>3</sup>
- ✦ In accordance with STANAG 4187 (last edition)
- ✦ Ignition of EIDS
- ✦ Low cost
- ✦ Generic SAU

**Pyro-MEMS: Merging of mechanics, electronics & pyrotechnics**



# Arming ability and reversibility

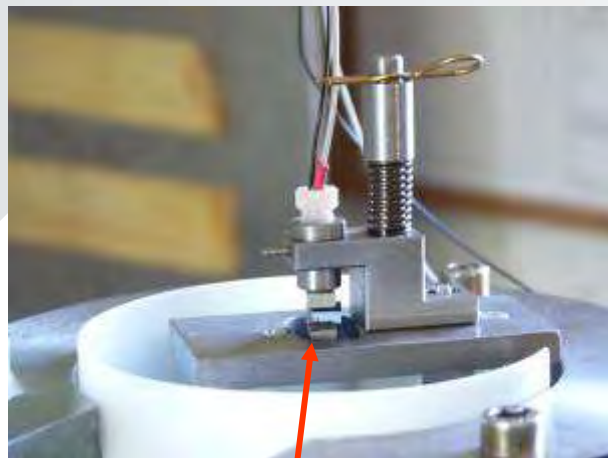


# 1. Pyro-MEMS®

- Preliminary study of  $\mu$ SAU
- **System level test: Warhead functioning demonstration**
- Preliminary study of medium caliber MEMS based SAU



# Demonstration $\mu$ SAU PyroMEMS® and in service missile warhead



**MEMS**

**Missile warhead**



**Two succesful firings of  
warhead  
(transmission and  
interruption)**

**Firing train for  
missile warhead OK**

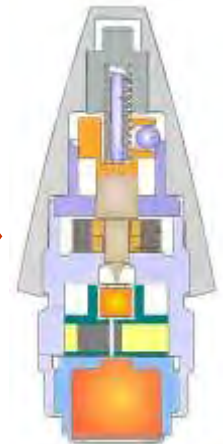
# 1. Pyro-MEMS®

- Preliminary study of  $\mu$ SAU
- System level test: Warhead functioning demonstration
- Preliminary study of medium caliber MEMS based SAU

MR251 Fuze  
(One safety)



$\mu$ DSA Fuze  
(Two safeties)



# Two safeties fuzing system

**VBCI (25M811)**

**Munition 25x137mm**

**MR251 Fuze**

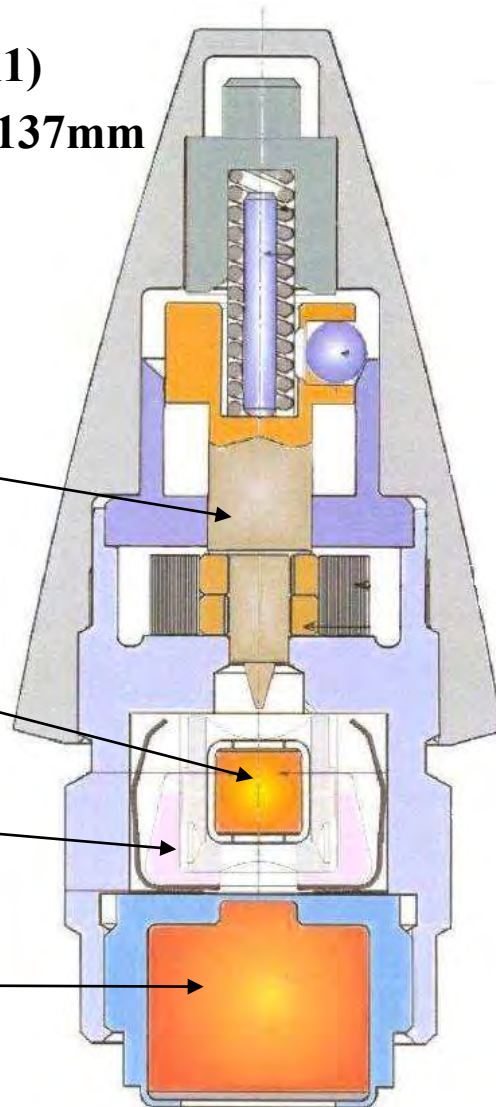
**(one safety)**

Firing pin

DA7 detonator

SAU

BF6 Lead



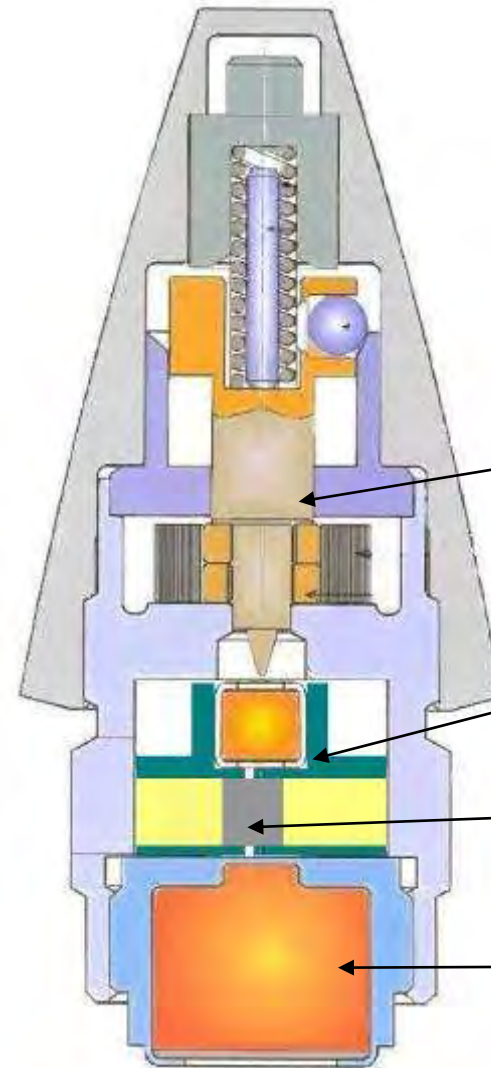
**μSAU Fuze**  
**(two safeties)**

Firing pin

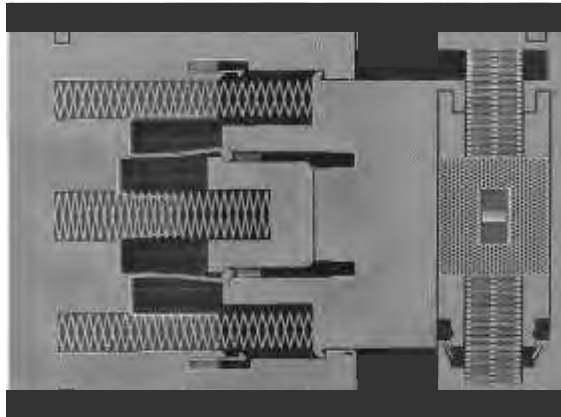
Detonator

MEMS based  
μSAU

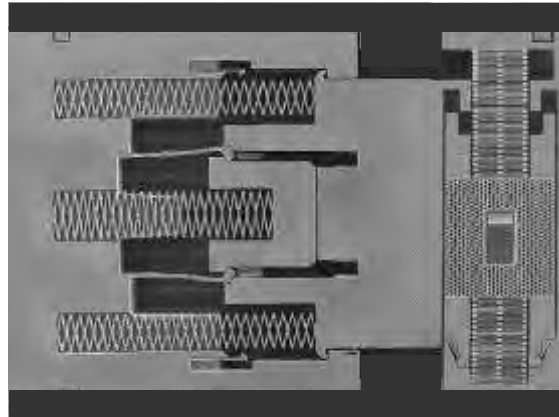
Lead



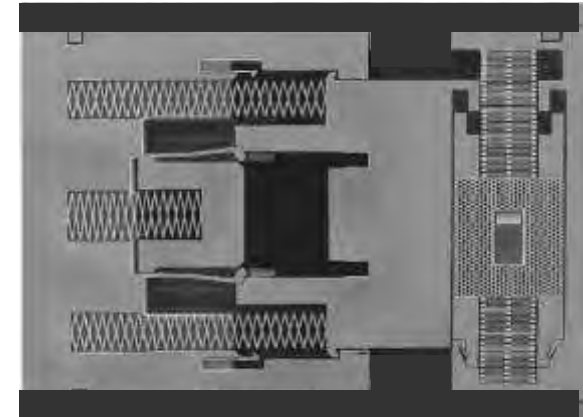
## Focus on MEMS elements



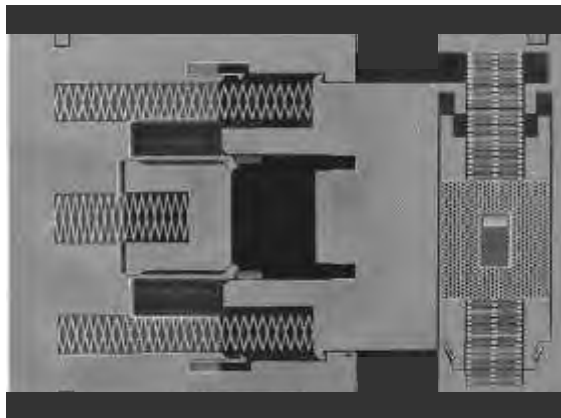
MEMS in safe position



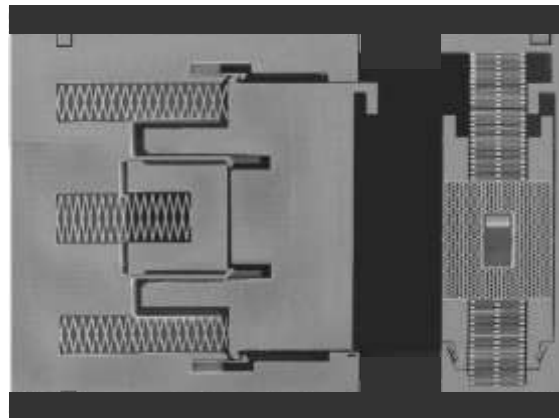
Axial safety unlocked



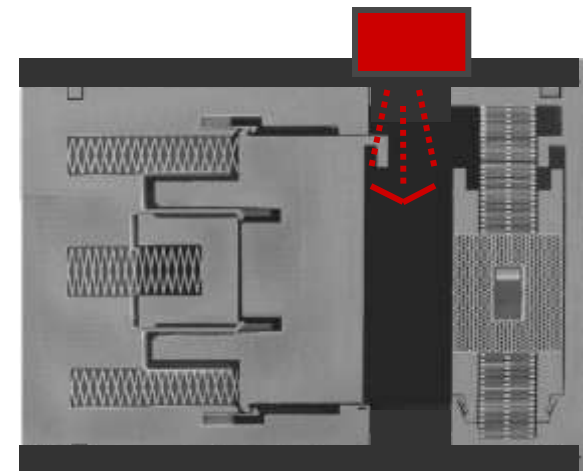
Progressive motion of the centrifugal safety



Unlocking of the shutter



MEMS in in-line position



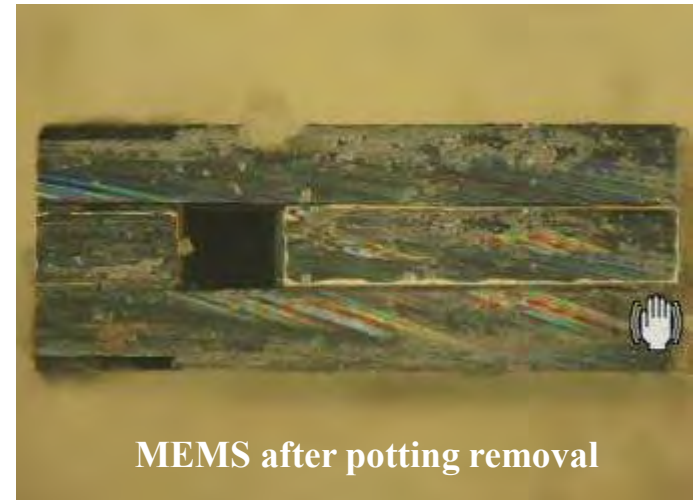
Firing !



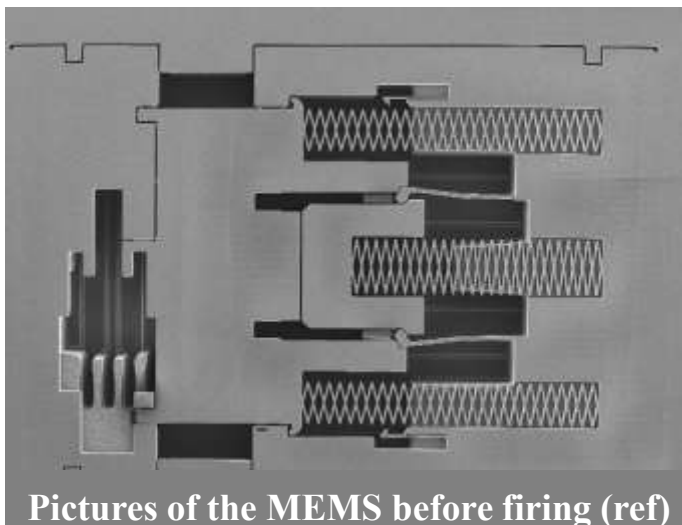
# High-G levels assessment



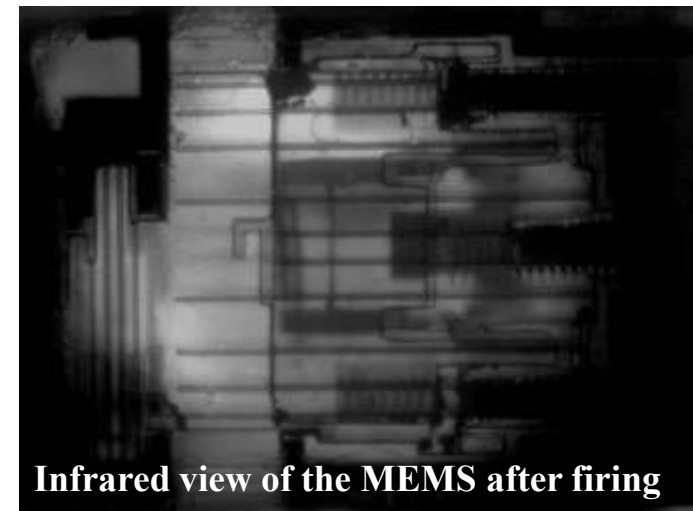
Carrier shell after firing



MEMS after potting removal



Pictures of the MEMS before firing (ref)



Infrared view of the MEMS after firing

## PyroMEMS® advantages for MK II

- ▶ Replacement of obsolete mechanical timer
- ▶ Innovation able to reduce the product price
- ▶ New step in the SAU miniaturization
- ▶ Better ammunition performances: 2nd safety
- ▶ Better safety performances
- ▶ MEMS technology is now mature and largely diffused (products and processes)
- ▶ A lot of application in ammunition domain (medium and large caliber, missiles, adjustable warheads) and in spatial domain (pyromechanisms) based on a generic component.

**Thank you for your attention**



# **Ceramic Capacitor Failures and Lessons Learned**

Presented to the 55<sup>th</sup> Annual NDIA Fuze Conference  
Salt Lake City, UT

**Patrick O'Malley and Darren Wang**  
**Dept. 2627**

**Henry Duong, Anh Lai and Zachary Zelle**  
**Dept. 0416**

**May 25, 2011**

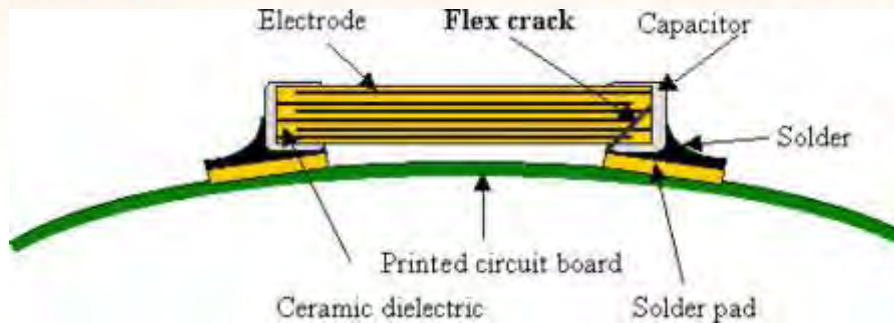
Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company,  
for the United States Department of Energy's National Nuclear Security Administration  
under contract DE-AC04-94AL85000.

Unclassified Unlimited Release

# **Sandia's Capacitor Experiences in FY10**

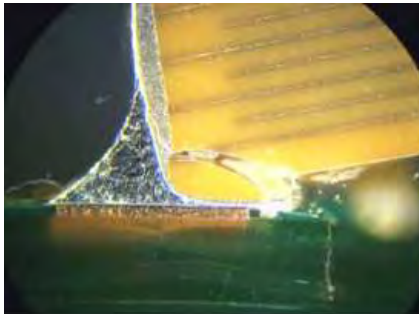
- **Sandia had two projects in FY10 that involved damage to ceramic capacitors**
  - **One where a commonly-available ceramic capacitor was a dominant failure mode**
  - **One where we deliberately damaged ceramic capacitors in order to understand their electro-mechanical response**

# Background: Capacitor Mechanical Failure



Failure of ceramic capacitors due to PCB flexure is a common problem.

M. Keimasi, et al., Flex Cracking of Multilayer Ceramic Capacitors Assembled with Pb-Free and Tin-Lead Solders, IEEE Trans. Device and Materials Reliability, Vol. 8, No. 1, March 2008



Example MLCC flex crack

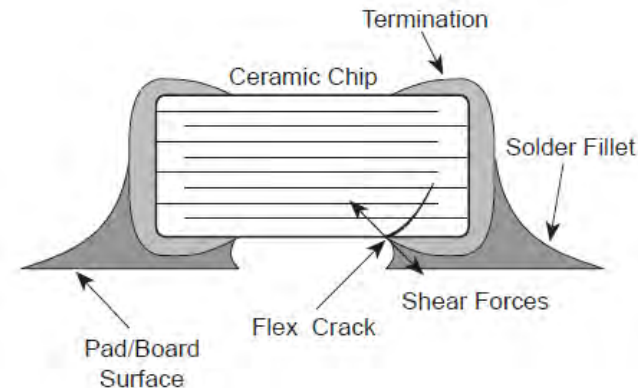


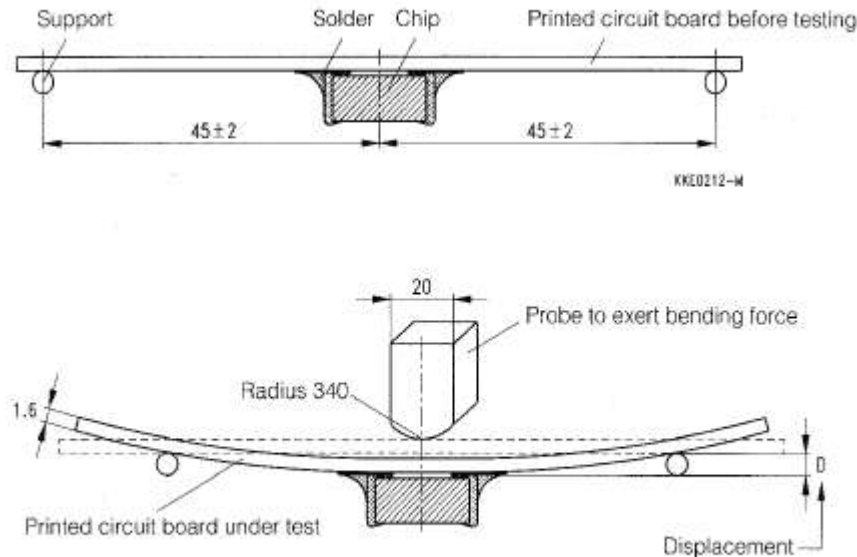
Diagram of an MLCC flex crack

<http://www.johansondielectrics.com/technical-notes/general/capacitor-cracks-still-with-us-after-all-these-years.html>

*Capacitance Monitoring While Flex Testing*, J. Bergenthal and J. Prymak, Kemet F-2110, reprinted 8/98, [http://www.kemet.com/kemet/web/homepage/kechome.nsf/file/f2110/\\$file/f2110.pdf](http://www.kemet.com/kemet/web/homepage/kechome.nsf/file/f2110/$file/f2110.pdf)

# Bend Testing

Bend testing is a common way to evaluate the strength of the capacitors – because it causes failures.



AEC-Q200-REV C, *Stress Test Qualification for Passive Components*,  
Method 005, Passive Component Board Flex / Terminal Bond Strength Test

See also:

- *Bend Testing, Methods and International Specifications*, AN0002 – Bend Testing, Issue 3, Syfer Technology Limited
- L. Mercado, B. Phillips, et al., *Handheld Use Condition-Based Bend Test Development*, IEEE Trans. Advanced Packaging, Vol. 29, No. 2, May 2006

## 3DDR: Small Ceramic Capacitor Failures

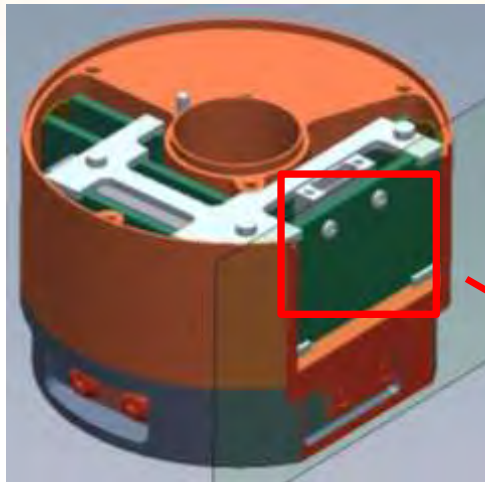
- 3DDR is an instrumentation data recorder
- Seven units were tested to failure in order to understand dominant failure modes
  - Root cause of failure was determined for all
- The failure mode for 4 out of the 7 was a small ceramic capacitor failure

	Unit	Cause of Failure
→	F1540	Capacitors C84/C85 (open)
→	F1541	Capacitor C91 (shorted)
	090804	Connector failure (caused by test)
	F1538	Unit failure (caused by test)
→	090805	Capacitor C91 (shorted)
	090806	No failure (yet)
→	090807	Capacitor C91 (shorted)

Each 3DDR unit failed after a number of mechanical tests.



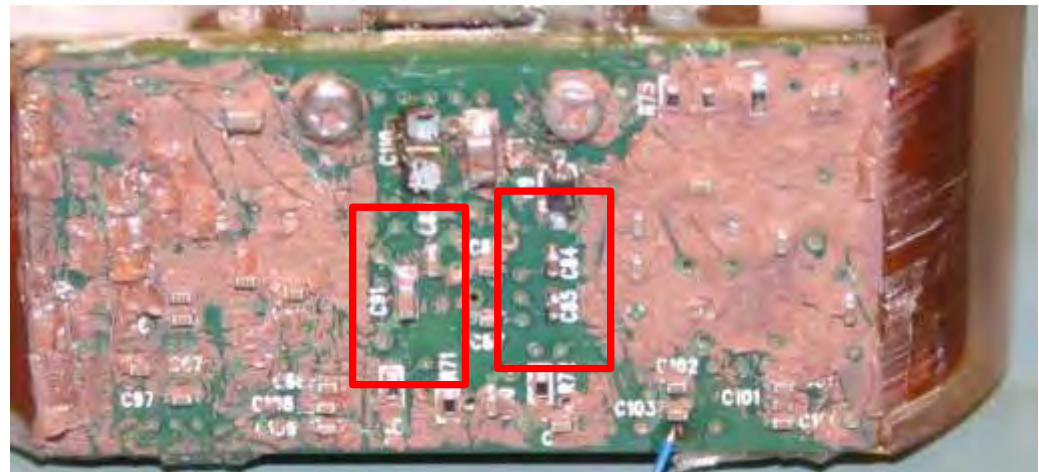
# Locations of Failed Capacitors



The dominant failure mode was capacitor failure in a very specific region of the back side of one rigid section of PCB.

0.42"

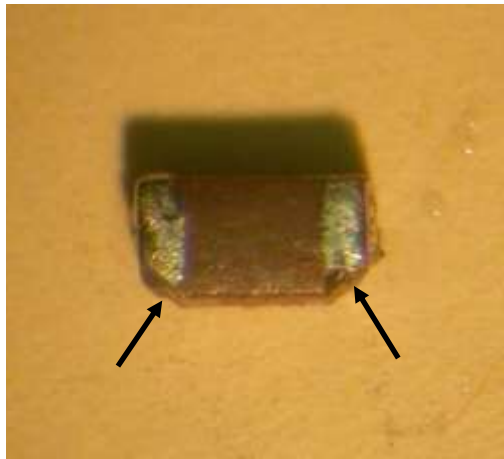
Capacitor C91 failed shorted 3 times while capacitors C84 (or C85) failed open once.



Locations of failed capacitors

# Example of Capacitor Failure

Damage to the capacitor is at the corners where the capacitor is soldered to the PCB



Side View



Bottom View



Top View

The capacitor is a COTS, 0603-package, X7R dielectric component



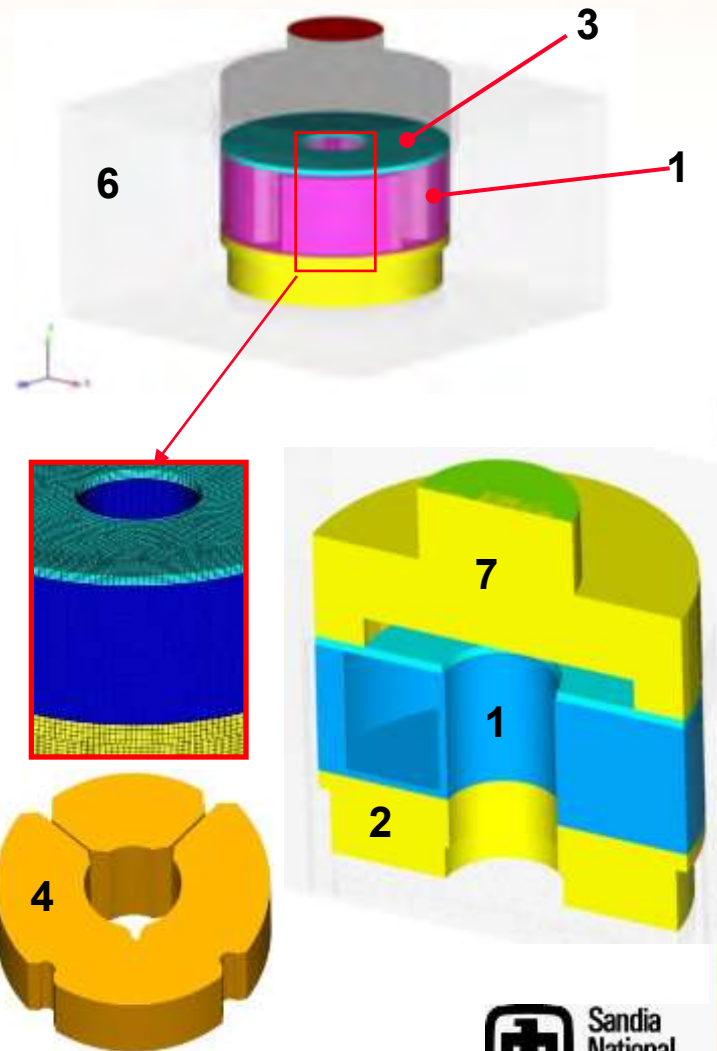
# Simplified Finite Element Model

A finite element model was developed to test the hypothesis that PCB deformation was causing the capacitors to break.

A simplified model with no PCB was developed to look at stresses in the potting material

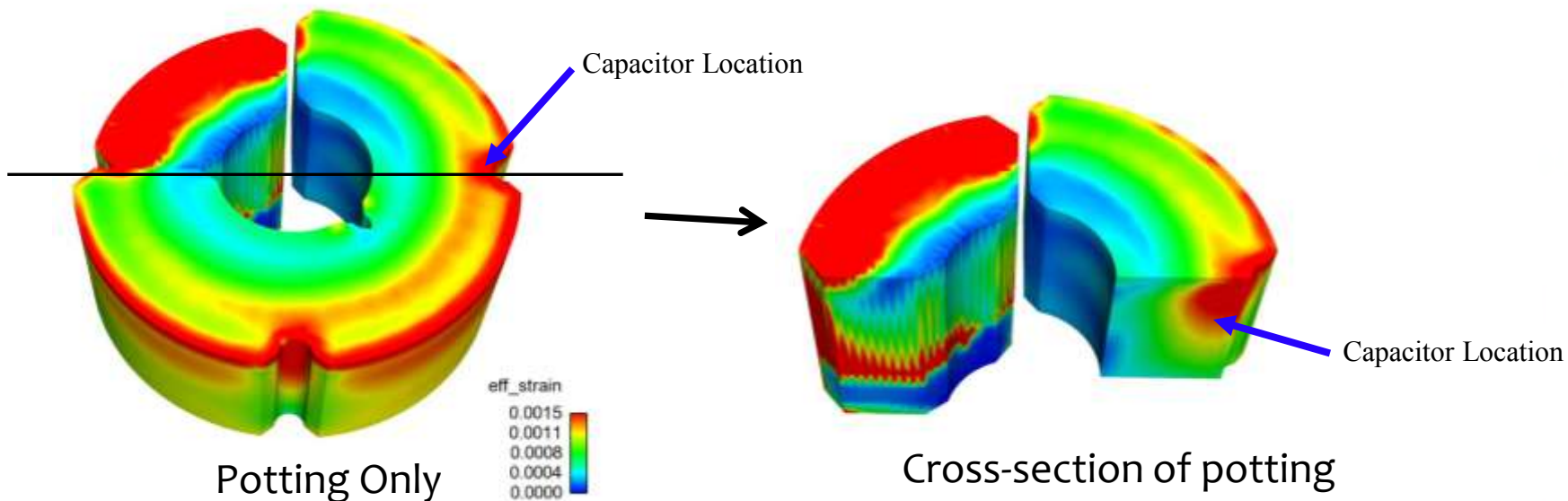
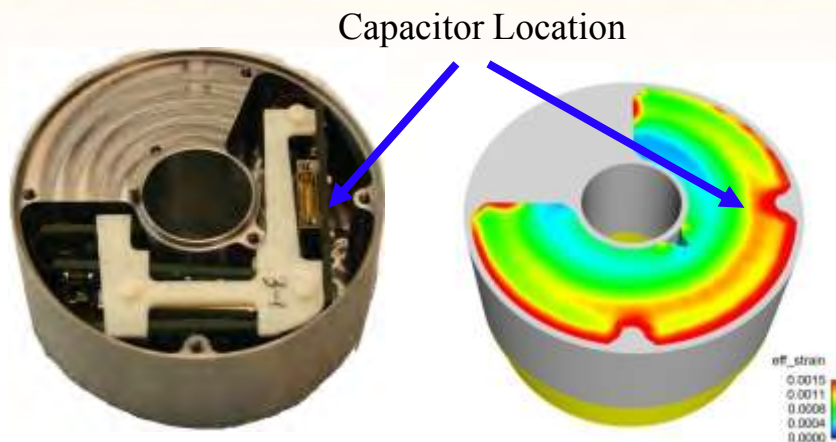
- Full 3D Hex Element model
- 7 Material Blocks
- Nodes = 480K
- Elements = 400K
- Element Length < 0.020-inch

Component	Block ID	Material Model
Upper Housing	1	4340 Steel Elastic-Plastic
Lower Housing	2	4340 Steel Elastic-Plastic
Housing Lid	3	4340 Steel Elastic-Plastic
Potting	4	Hysol Elastic (Ref. Adolph)
Battery Pack	5	Aluminum Elastic
Fixture	6	Aluminum Elastic
Pressure-Bar/Retaining ring	7	Aluminum Elastic



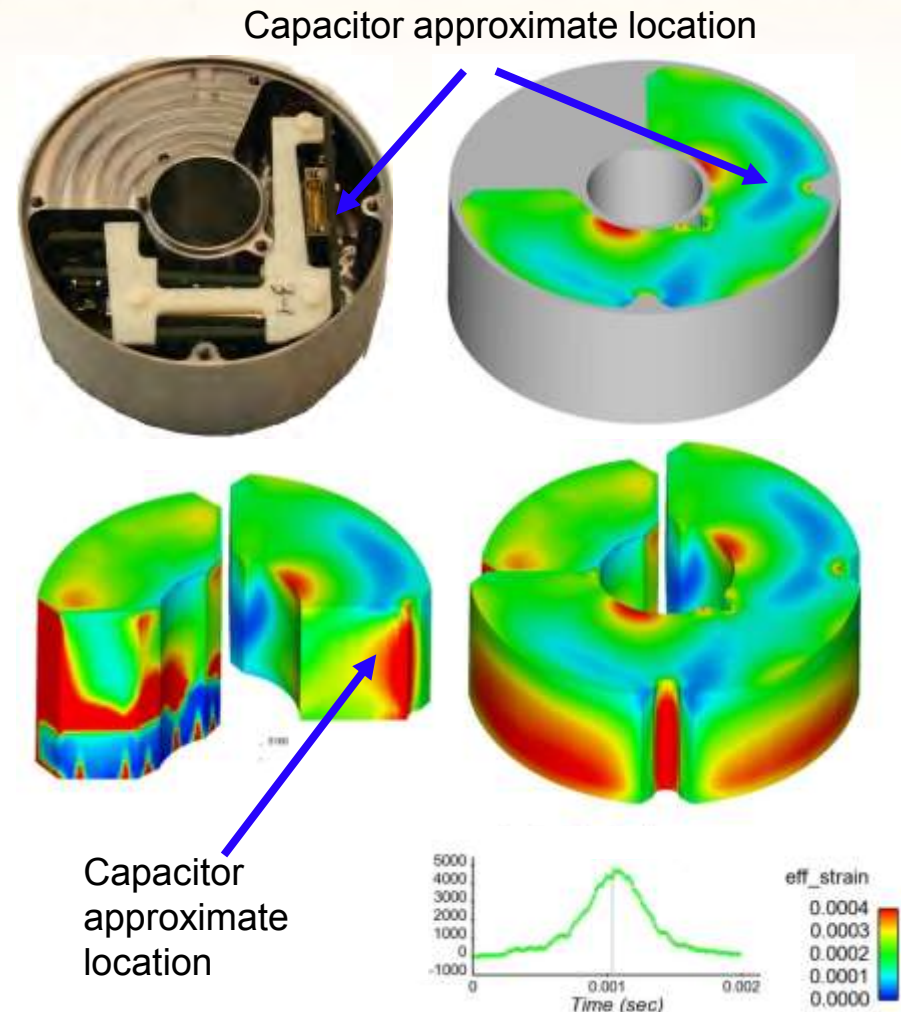
# Static Loading Results

- No yielding in potted 3DDR housing
- High stress in potting near lid
- Main potting maximum effective strain =  $1500\mu\epsilon$
- ***High strain at capacitor location***



# Dynamic Loading Results

- Acceleration loading applied at bottom of fixture
- No yielding in potted 3DDR housing
- High stress in potting propagate from bottom up
- Main Potting Maximum effective strain =  $400\mu\epsilon$
- ***Noticeable strain at capacitor location***





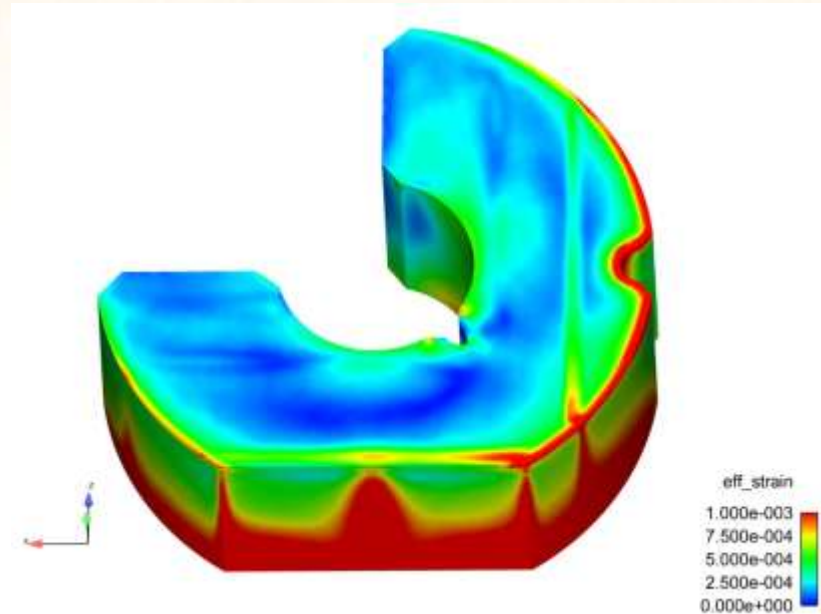
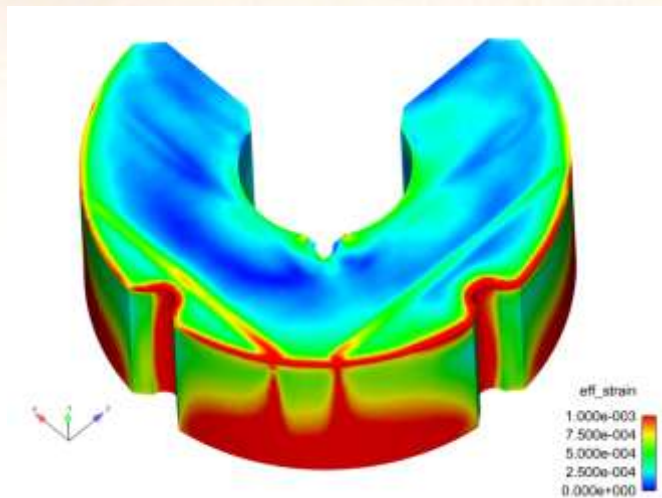
## Higher Fidelity Model

A higher fidelity model was developed that included the PCB in order to understand its strain.

- 1.3M elements, 1.4M nodes
- Approximately 750K elements for the potting material
- Linear elastic PCB material model



# High Fidelity Model Results

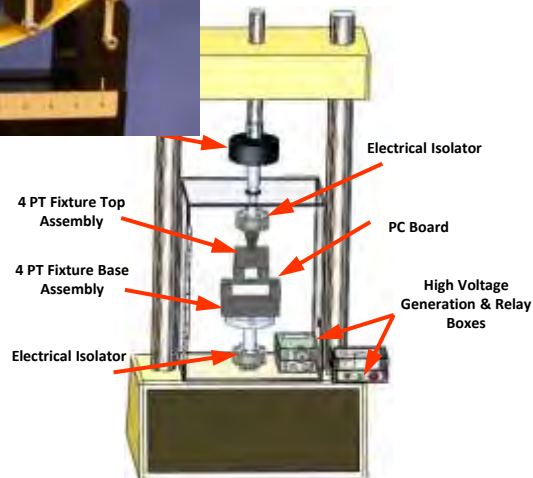


- Results based on a measured acceleration input
- Model results show that there is a strain of approximately  $500\mu\epsilon$  at the surface of the PCB near where the capacitors failed
- Strain is not enough\* to break the capacitor off the PCB in one test – modeling matches experiment

\* - Using Keimasi (2008) as the reference for necessary strain to induce flex cracking in small ceramic capacitors

# Breaking Capacitors – On Purpose

- We took ceramic capacitors with three dielectrics and subjected them to mechanical, electrical and combined tests



## Electrical Tests

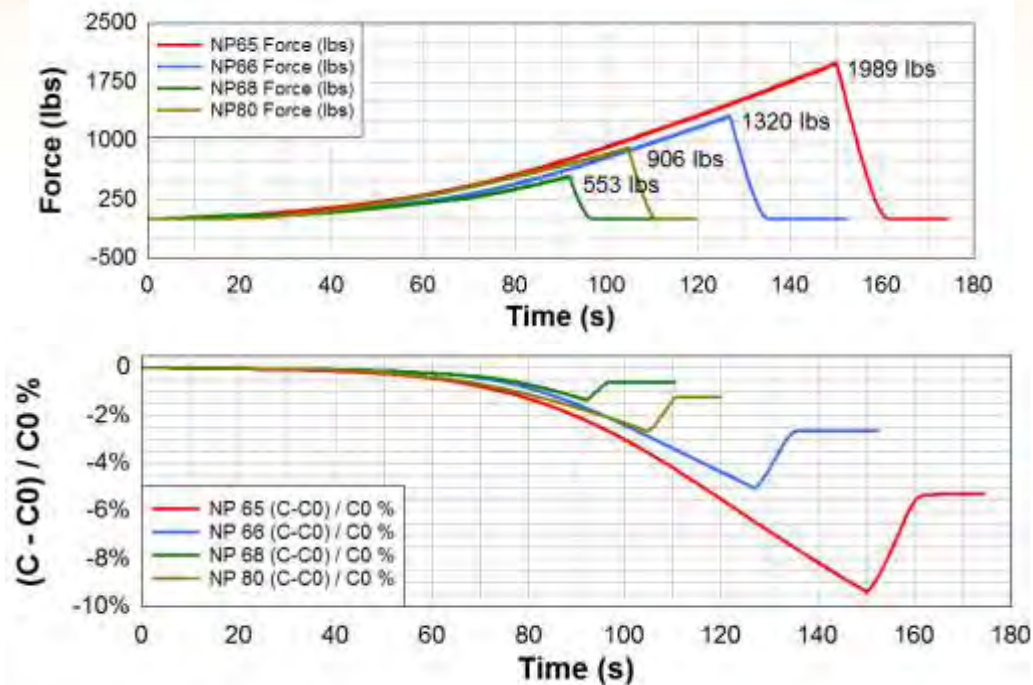
		Nominal	Breakdown Voltage	Pulse Discharge
Mechanical Tests	Nominal		Benchtop Breakdown Voltage Characterization	Benchtop Pulse Discharge Characterization
	Static Compression	Isolated Mechanical Compression	Breakdown Voltage under Compression	Pulse Discharge under Compression
	Static Bending	Isolated Mechanical Bending	Breakdown Voltage under Bending	Pulse Discharge under Bending

## Three Results

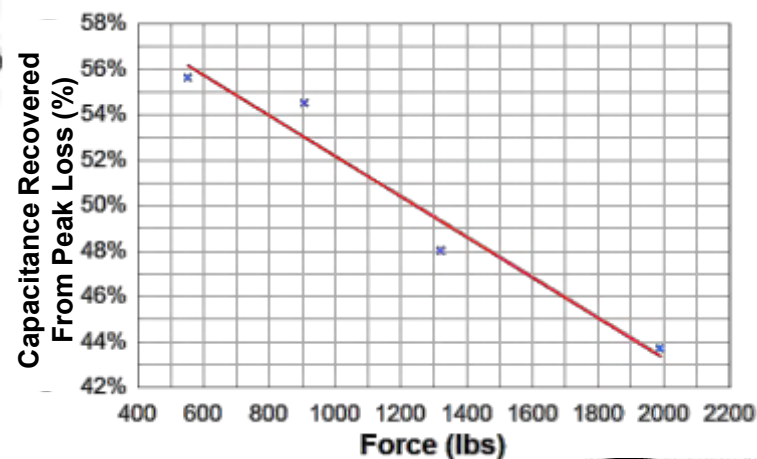
- 1. Capacitance recovery after mechanical compression**
- 2. Effect of reflow soldering on mechanical failure**
- 3. Capacitance change caused by mechanical compression**



# Capacitance Recovery



One dielectric showed reduced capacitance after mechanical compression



# Effect of Reflow Soldering on Mechanical Strength

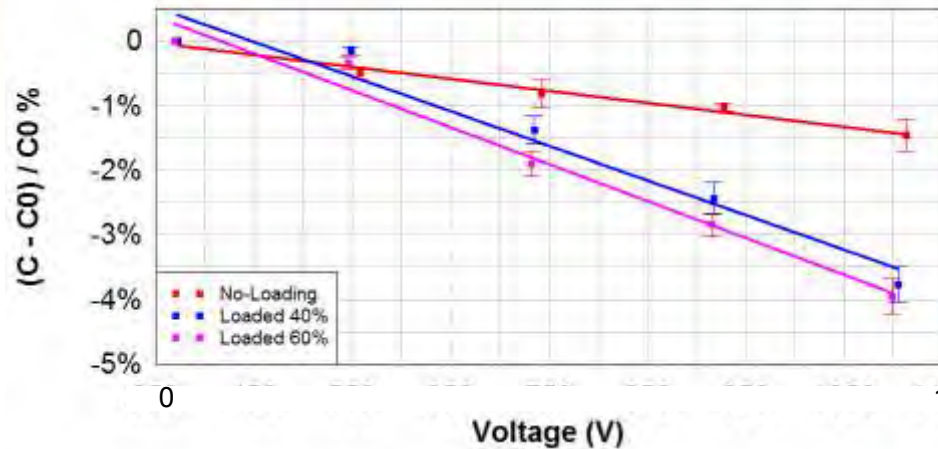
- We found that reflow soldering these capacitors causes them to fail at lower mechanical stresses than using a non-solder attachment technique
- Manufacturer soldering guidelines were followed

Average compressive displacement at failure (mils)

Type	Solder	Conductive Epoxy
A	5.60	8.77
B	6.71	16.0
C	9.65	18.5

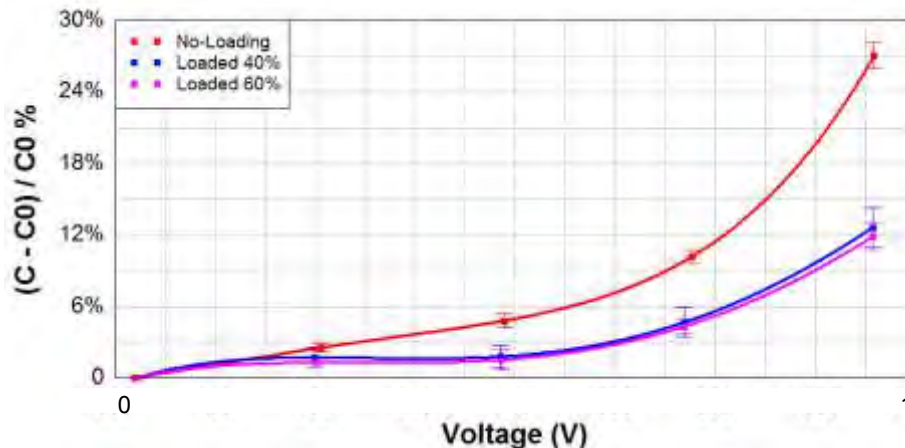
# Capacitance Change During Mechanical Compression

## Dielectric B



- Dielectric B showed a diminished capacitance when compressed
- Dielectric C showed a diminished increase in capacitance when compressed

## Dielectric C



# Summary

- **PCB flexure is one sure way to damage even tiny capacitors**
  - But modeling and simulation, combined with existing experimental data, can help predict this
  - Even relatively low fidelity modeling can help qualitatively
- **Ceramic capacitors can change characteristics during and after mechanical stresses**

# Acknowledgements

Many thanks to the sponsor and collaborators who helped with this work.

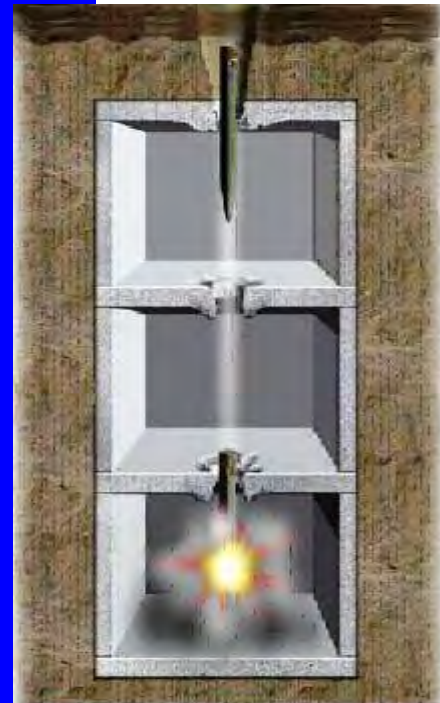




*Void Sensing Fuze (VSF)  
Product Improvement Program (PIP)  
Transition of German Technology to Meet  
American Warfighter Needs*

*55<sup>th</sup> Annual NDIA Fuze Conference  
24-26 May 2011*

*Co-presenters:  
Dr. Helmut Muthig, TDW  
Dale Spencer, Kaman Precision Products*





# *Foreword*



- ✦ **This joint presentation by the Defense Threat Reduction Agency (DTRA), Kaman Precision Products, and MBDA/TDW highlights significant respective management and technology success in integrating across countries, companies and cultures for a DoD Product Improvement Program (PIP). The VSF PIP of the TDW Programmable Intelligent Multi-Purpose Fuze (PIMPF) into a US produced three inch fuzewell is an impressive story involving the cooperation of USAF, Navy, and DTRA. This effort puts to rest many concerns and reservations often held for programs requiring international cooperation.**
- ✦ **This presentation is dedicated to the memory of the late *Lt. Col. Herbert J. Smith III* who was a driving force in the inception of this program and who believed so strongly in the benefit to the American Warfighter that this technology and cooperation offers.**





# Agenda



- **An overview of the DTRA Void Sensing Fuze Product Improvement Program**
- **Overview of the functionality of the Fuze**
- **VSF Cannon Testing at Meppen, Germany**
- **VSF Cannon Testing with USAF**
- **VSF Sled Testing with Navy**
- **Environmental Validation Testing Efforts**
- **Transition of VSF under a JCTD to US Weapons**





# *Historical Background*



➔ **OSD Comparative Test Office and Defense Threat Reduction Agency (DTRA) sponsored Foreign Comparative Test (FCT) Program to evaluate the German's Programmable Intelligent Multi Purpose Fuze (PIMPF)**

- PIMPF is a qualified fuze, currently in service in the Taurus KEPD 350 and has been selected for the Norwegian Naval Strike Missile
- FCT program evaluated the ability of the PIMPF to penetrate hard, deeply buried targets, sense and count layers and voids as it penetrates, and then detonate in a specific void as programmed

➔ **Recommendation accepted to conduct a Void Sensing Fuze (VSF) Product Improvement Program (PIP) to repackage current PIMPF into a form factor compatible with US Weapon Fuzewells**



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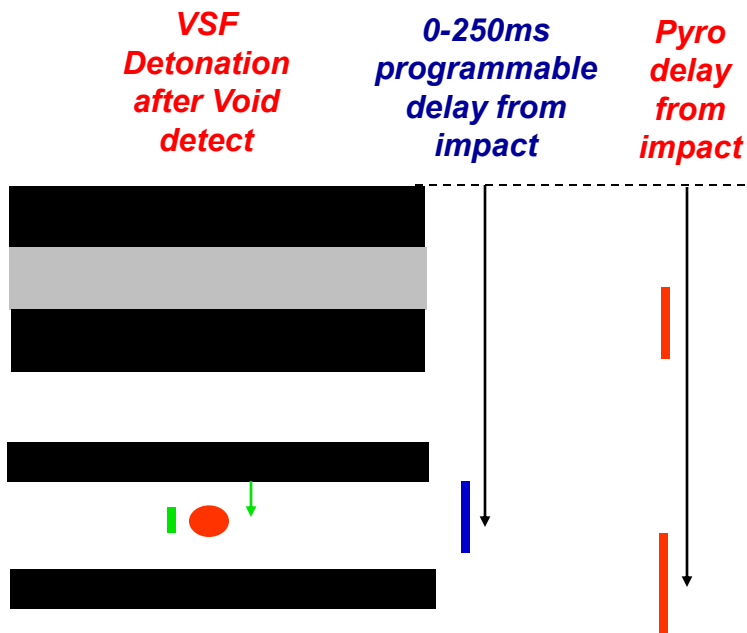
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# Benefits of Smart Fuzing

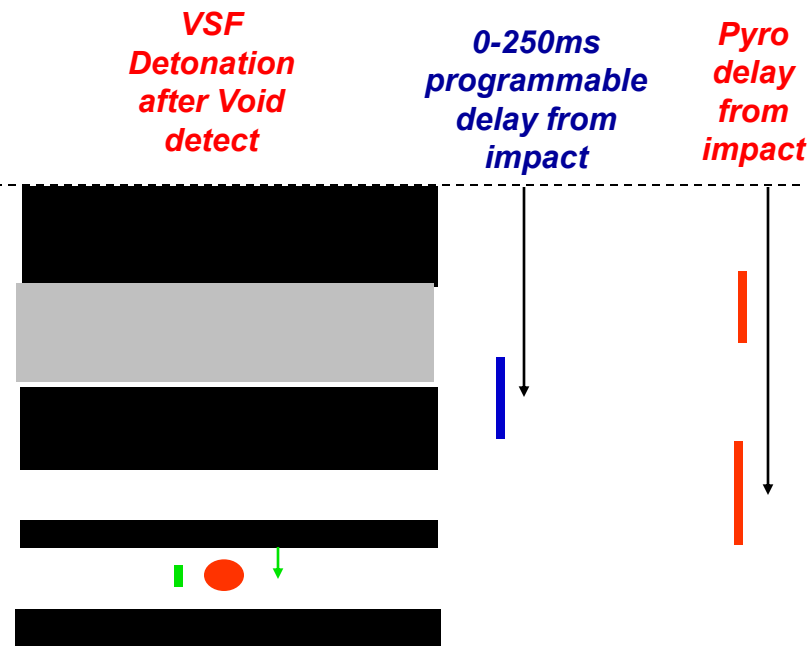
*A Void Sensing Fuze Finds & Fires in Programmed Void*



## PLANNED TARGET



## ACTUAL TARGET



*Void Sensing Fuze Provides Intelligence to Fire at Precision Location to Maximize Weapon Effectiveness*

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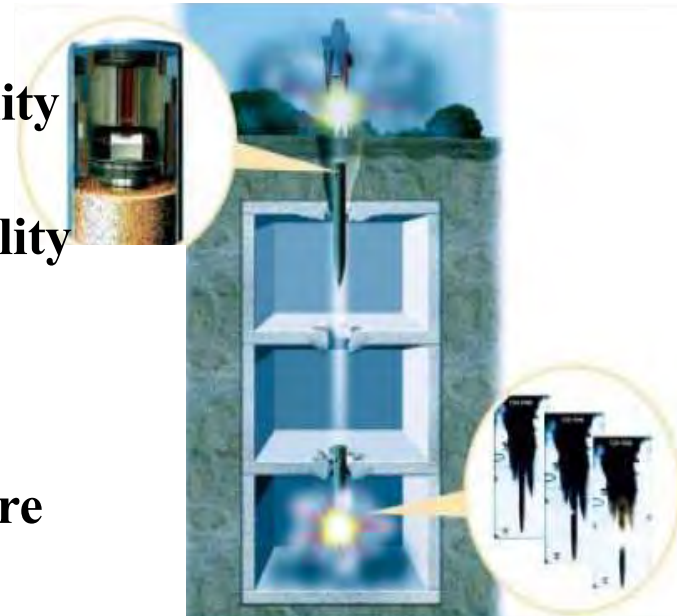


# ***Void Sensing Fuze Objectives***



***Repackage the Programmable Intelligent Multi-Purpose Fuze (PIMPF) into a form factor compatible with US weapon fuzewells***

- **Conduct trade studies to investigate compatibility with US weapon systems**
- **Demonstrate original void/layer sensing capability**
- **Conduct limited environmental/qualification testing**
- **Conduct USG Cannon/Sled testing to confirm functionality and serve as a risk reduction before USG integration**
- **Provide residual VSF for JMEWS development and make available for other transitional US partners**



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# *VSF Program Requirements*



- VSF must meet NATO Standard Agreement 4187 and MIL- STD-1316E
- VSF must be sized to enable incorporation into standard US weapon fuzewell
- VSF must function within the operating environments of the host weapon system
- VSF must sense/count layers and voids as it penetrates a hard target and detonate at a planned point within the target
- VSF must be field-level and cockpit programmable





# *VSF PIP Phases*



- ***Phase 1 - VSF Modification and Demonstration ~ Completed***
  - Trade Studies (capacitors vs batteries, connectors, modifications for gravity bomb applications)
  - Initial repackaging design
  - Component level environmental / shock testing
  - Engineering Evaluation Unit (EEU) design
  - Contractor led cannon testing (TDW at Meppen, Germany)
- ***Phase 2 – US Pilot Assembly and Verification Testing ~ Working***
  - Pilot production of multiple fuzes - *Completed*
  - Production acceptance testing - *Completed*
  - Environmental testing - *Pending*
  - USG Production Verification Testing - *Completed*
    - Cannon Testing with USAF at Eglin AFB – Risk Reduction to Sled Testing
    - Sled Testing with US Navy at China Lake





# *VSF PIP Participants*



- *DTRA*
- *TDW / MBDA Missile Systems (Germany)*
- *KAMAN Precision Products*
- *AFRL ~ Eglin AFB*
- *NAVAIR ~ China Lake (SNORT)*
- *PMA-280 Joint Multi-Effects Warhead System*



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# *Roadmap to Success*



## **VSF Program Milestones**

- ✦ **DTRA funds FCT of PIMPF**
- ✦ **NNMSB Safety Review of PIMPF**
- ✦ **FCT Test of PIMPF**
- ✦ **DTRA awards Contract for VSF Product Improvement Program (PIP)**
- ✦ **VSF PIP SRR**
- ✦ **VSF PIP Preliminary Design Review (PDR)**
- ✦ **FISTRP Tech Assist Safety Review**
- ✦ **VSF Critical Design Review (CDR)**
- ✦ **VSF / TDW Validation Cannon Tests ~ Germany**
- ✦ **VSF Risk Reduction Cannon Tests ~ Eglin**
- ✦ **VSF Validation Sled Testing ~ Navy SNORT**
- ✦ **VSF Final Environmental Testing ~ Pending**



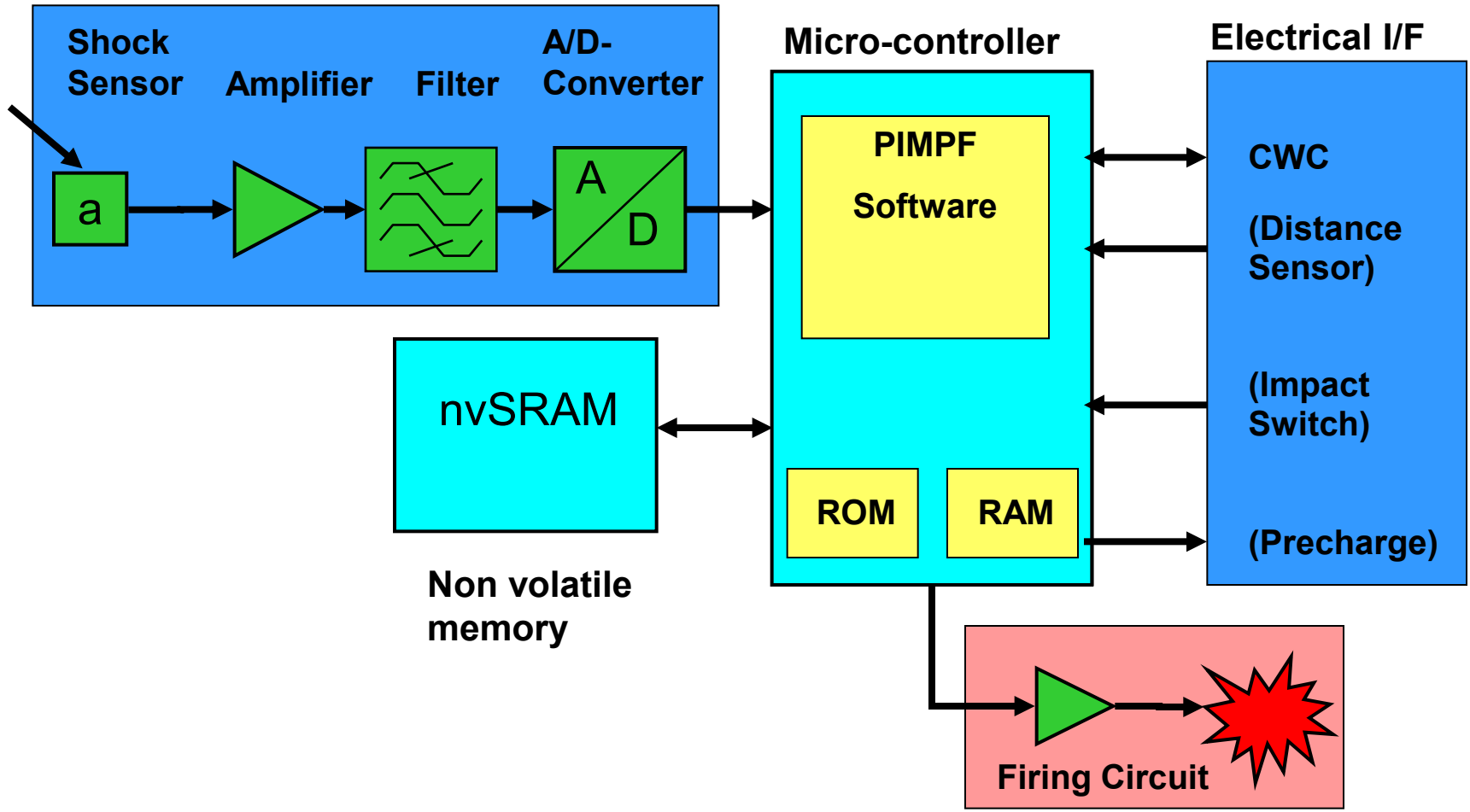
# ***Technology to Detect Voids with Penetrating Weapons***

**Dr. Helmut Muthig,  
Managing Director, TDW / MBDA**



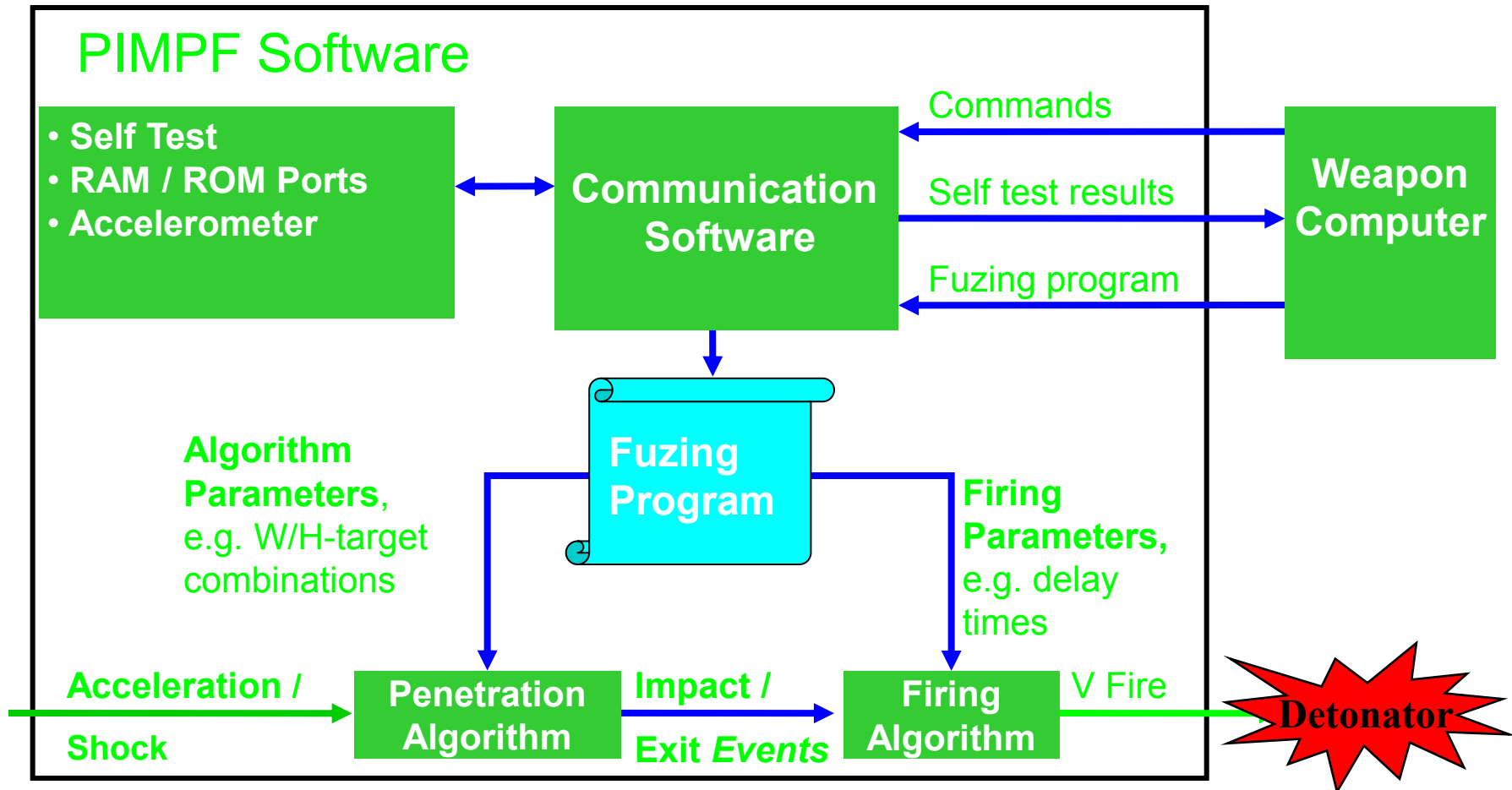
# PIMPF TDD

## Functional Block Diagram





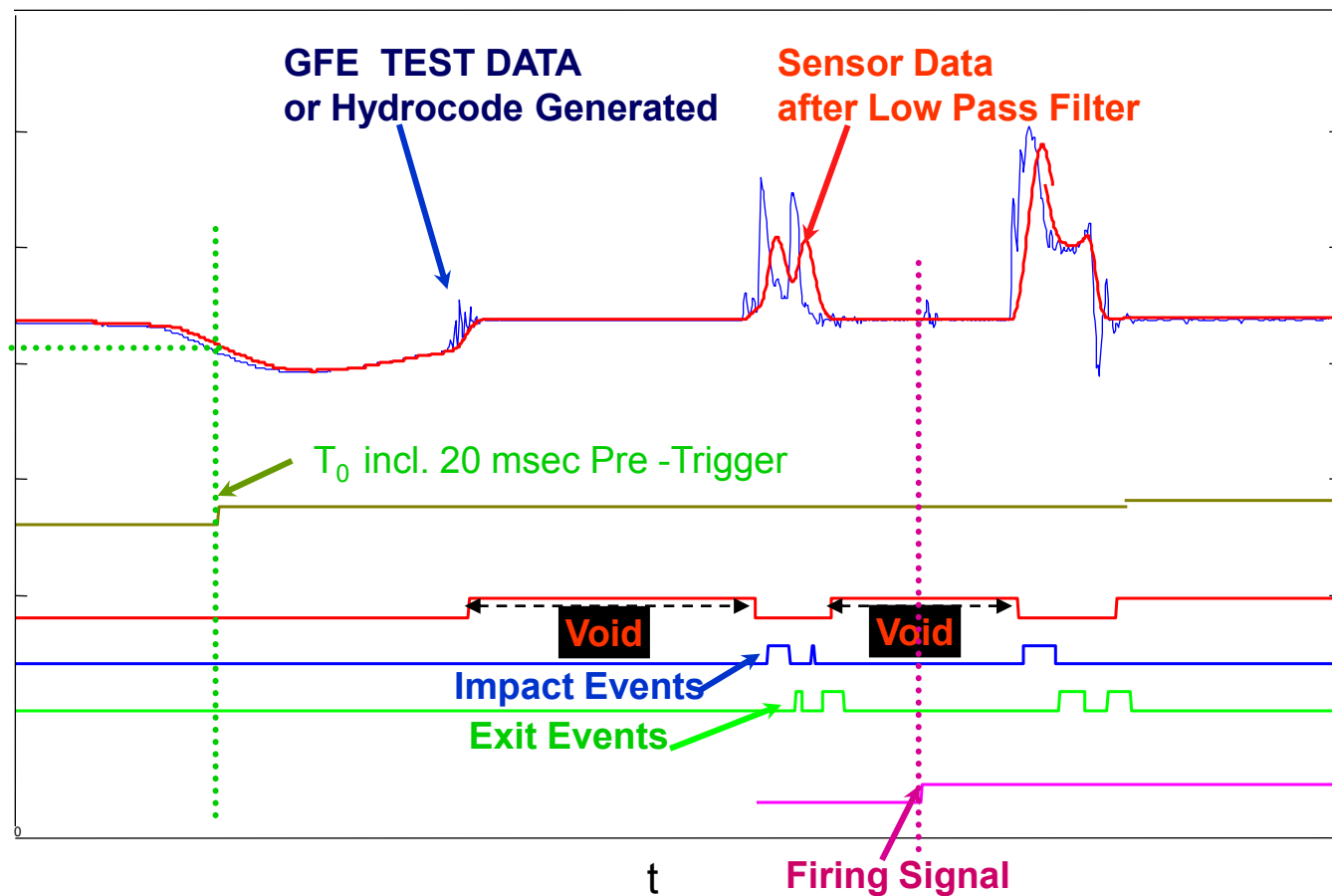
# Functional Description ~ TDD



# TDD Performance Prediction



## VSM internal data logging capabilities







# *Contractor Testing Overview*



- ✓ **Hardware in the loop testing**
- ✓ **Extended Temperature testing**
- ✓ **Booster Initiation Testing**
- ✓ **Detonator / Hand Safe Testing**
- ✓ **Acceleration (High Shock) testing**
- ✓ **Basic Environment /Robustness Testing**
- ✓ **Shock/Impact Testing at Meppen**
- ☐ **U.S. Environmental Testing**



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# VSF Validation



- Detonator Safety Test
- Pyrotechnical I/F Test
- Basic Environmental and Robustness
- Test – Ulm Germany
- Explosive Compatibility Test
- CV / Penetrations Tests at WTD 91
- CV / Environmental Test

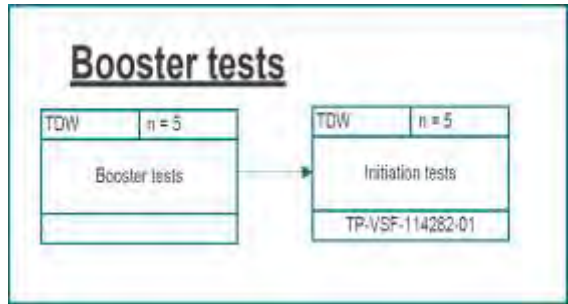


Test report  
Detonator safety  
Void Sensing Fuze (VSF)

Test Report  
Pyrotechnical I/F Test  
Void Sensing Fuze (VSF)

**VSF**  
Detonator Safety  
Report

**VSF**  
Pyrotechnical I/F  
Report





# *VSF - TDW Validation Field Tests*



Test #	Date	Target	Lessons Learned
1	6 June 2009	1 -- 2' 9.5" Reinforced concrete	Thread Design on Booster Cup to Fuze Housing Redesigned -- Threaded Booster Facilitates Testing
2	15 June 2009	2 – 15.5" Reinforced concrete plates	Rotor Flange angle relieved Booster Cup Teflon Damping Ring redesigned for greater robustness
3	28 Oct 2009	1 – 5'5"	Enhancements to flex interconnect cable and addition of flex retaining bracket
4	23 Feb 2010	2 – 15.5" Reinforced concrete	TDW Contractor Led Cannon Tests verified CIPPS: APP Functionality; Entry/Exit Detection @ critical impact velocities and angles

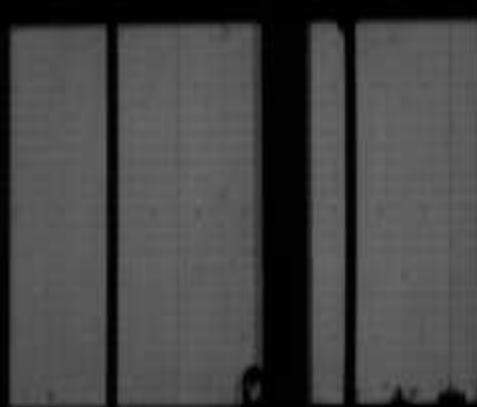


# *VSF Contractor Penetration Testing Cannon Test ~ Double Concrete Plate*



20000 fps

+00.00000



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*VSF ~ USG Testing*  
*Dale Spencer*  
*Kaman Precision Products*







# *VSF ~ USG Cannon Risk Reduction Testing*



- **Total of 4 Cannon Test Events**
- **Cannon Test #1 - Eglin Air Force Base**
  - **Objective:** Survivability and Functionality
    - Repeat of the TDW Contractor Validation Test conducted previously to confirm the integrity of the design high G load, and verify TDD ability to detect void layer
  - **Confirmation:** No Test
    - Pusher Plate Failed due to material failure
    - Fuze Burned, TDD Recorded and Functioned Post Test

**“The fact that the TDD survived the extreme gun gas pressure and extremely high gas temperature is remarkable.”**





## *VSF ~ USG Cannon Test #2*



### ✦ **Cannon Test #2 - Eglin Air Force Base**

#### ✦ **Objective:** Survivability and Functionality

- ✦ Repeat of the TDW Contractor Validation Test conducted to confirm void/layer detection, survivability, and functionality of the VSF at distance from gun barrel to front of first target layer
- ✦ Verify VSF integrity and exposure to **High Lateral G loading**

#### ✦ **Confirmation:** VSF Complete Success Despite Warhead Breakup

- ✦ Fuzewell separates from the penetrator and travelled about 30 ft from the final concrete target slab
- ✦ Fuzewell sustained severe deformation with fuze retaining ring lock-up
- ✦ TDD functioned as programmed despite violent separation from penetrator that was exposed to severe tail slap
- ✦ Void Sensing Fuze remains intact and undamaged in damaged Fuzewell
- ✦ Final exit & fire signal generated successfully as programmed despite violent separation from penetrator



## *VSF ~ USG Cannon Test 3 & 4*



### ✦ Cannon Test 3 & 4 ~ Eglin Air Force Base

#### ✦ **Objective:** Survivability and Functionality

- ✦ Test #3 is to confirm multiple void/layer detection, survivability, and functionality of the VSF through double concrete plate
- ✦ Test #4 is to confirm multiple void/layer detection, survivability, and functionality of the VSF through multiple concrete plate and compact soil

#### ✦ **Confirmation:** Complete Success both tests

- ✦ The TDD functioned as programmed; traces show entry and exit from each concrete target and difference in deceleration levels between concrete and soil configuration
- ✦ The final exit & fire signals were generated as planned
- ✦ No damage to VSF Fuzewell or VSF
- ✦ Inert VSF with Kaman HIDR in Booster Cup ~ reused multiple times



## *VSF ~ USG Sled Testing*





## ***VSF ~ USG Sled Testing***



- ➔ **Total of 3 USG Sled Test Executed Successfully ~ China Lake**
- ➔ **Objective: Verify Survivability, Functionality, and ability for VSF to command fire signal at appropriate Pre-Programmed Void Layer Tests**
- ➔ **VSF Sled Test Parameters included:**
  - ➔ Void Sensing Fuze's conf/w Live Detonator/Inert Lead to enhance data collect & verify 'Fire' Command ~ (HIDR)
  - ➔ Pre/Post Test modeling for Risk Reduction, Comparison, and Model Update
  - ➔ Penetrator configuration designed to mitigate lessons-learned from PIMPF (FCT)
  - ➔ Penetrator engineering designs minimal for VSF



# *VSF ~ USG Sled Testing Snapshot*



## *Primary Objective: Functionality & Survivability*

### ➔ VSF Sled Test #1

- ➔ Repeat of the PIMPF FCT test to confirm no capabilities were lost between PIMPF and VSF during the PIP program
- ➔ Verify VSF integrity and exposure to high lateral G loading

### ➔ VSF Sled Test #2

- ➔ Demonstrate VSF ability to detect the void space behind known target and issue a fire signal after exiting that target

### ➔ VSF Sled Test #3

- ➔ Demonstrate the ability of the fire signal to initiate the detonator ~ HIDR
- ➔ Determine the ability of the VSF to detect various target thickness and issue appropriate entrance and exit signals

### ➔ Confirmation on all 3 USG Sled Tests: **Complete Success**

- ➔ The TDD functioned as programmed in all test scenarios
- ➔ The final exit & fire signals were generated as planned
- ➔ The TDD traces clearly showed the entry and exit from each target set
- ➔ HIDR used during Test #3 showing useful x,y,z axial data



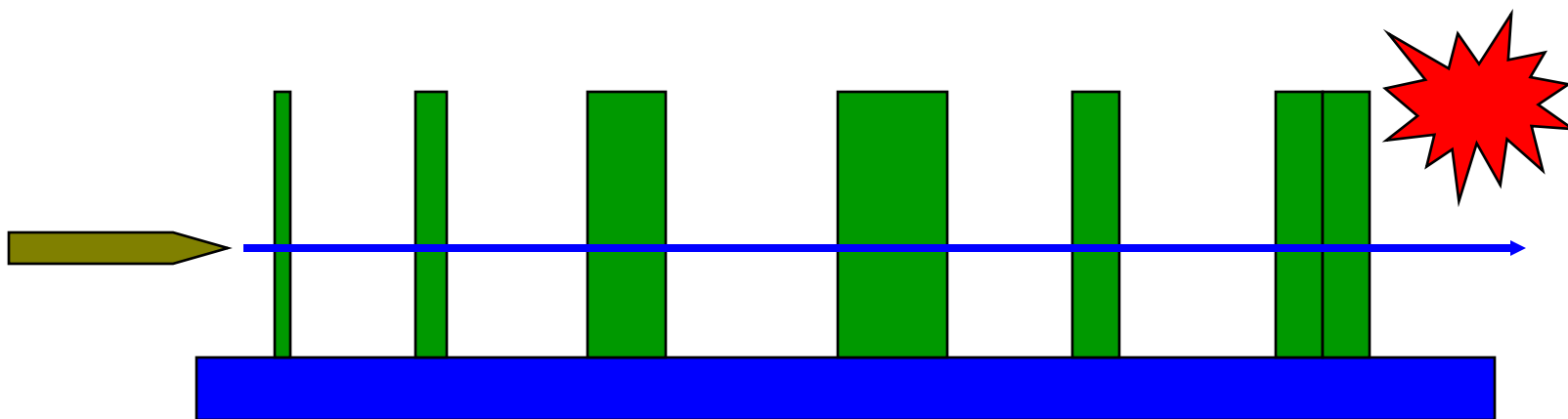


# *VSF ~ USG Sled Testing Snapshot*

*Primary Objective: Functionality & Survivability*



## *Example of VSF Sled Testing Multiple Target Penetration*



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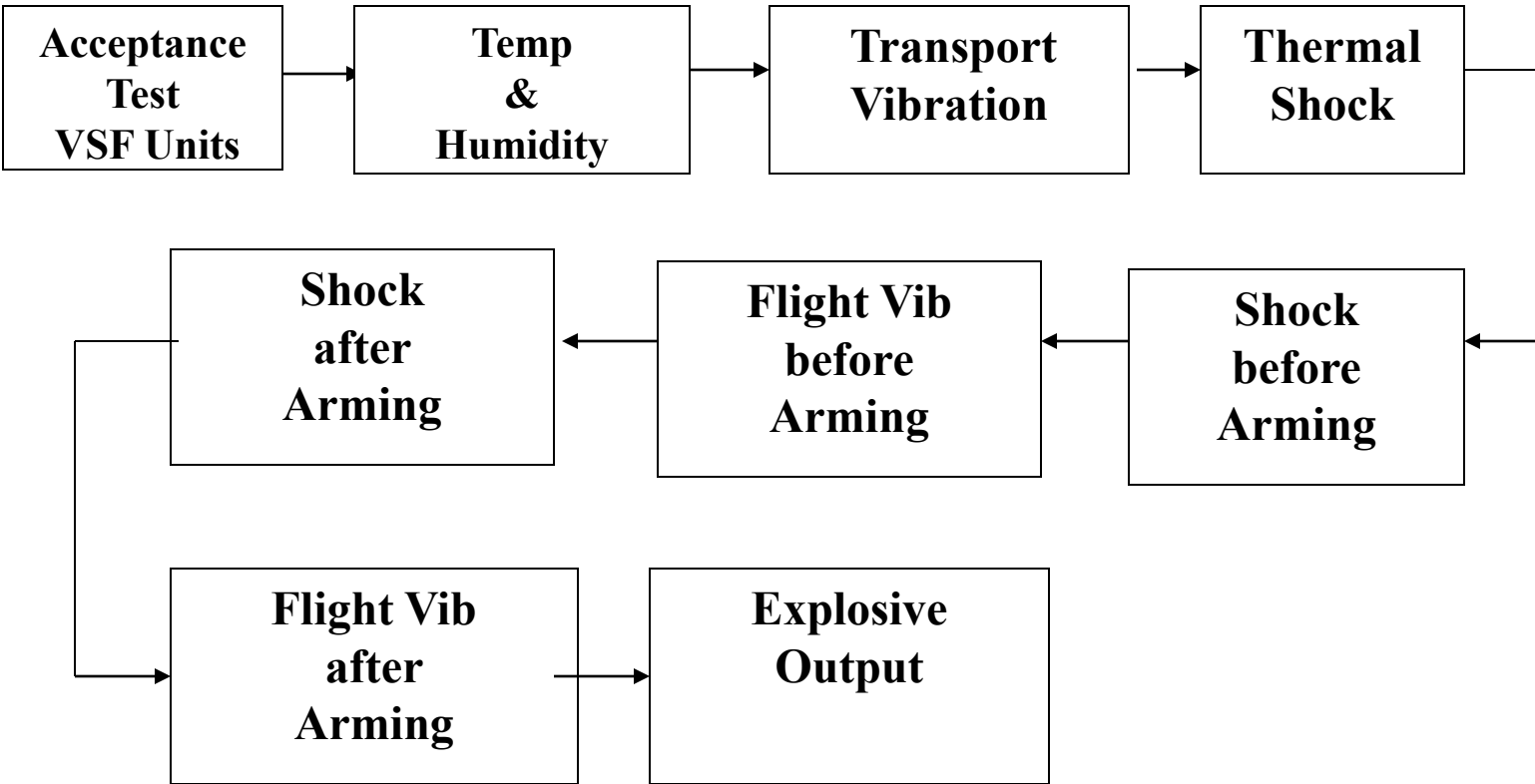




# Environmental Verification Testing



➤ **Objective:** verify the capability of the VSF to perform within the required specifications prior to, during and following exposures to various environments – **Pending**





# *VSF ~ Transforming Future Warfighter Capability & Integration*





# *OSD Perspective*

Chuck Kelly

OUSD (Acquisition, Technology & Logistics)  
Land Warfare and Munitions



(703) 695-1772  
DSN 225-1772  
[charles.kelly@osd.mil](mailto:charles.kelly@osd.mil)



# Agenda

- **OSD/AT&L Organization & Leadership Perspective**
- **Budget Perspective**
- **Department-level Fuze Initiatives**



## Secretary of Defense

Hon. Robert Gates



## Deputy Secretary of Defense

Hon. William Lynn

### Under Secretary of Defense for Acquisition, Technology & Logistics

Hon. Ashton Carter



Principal Deputy :  
Hon. Frank Kendall



### Secretary of the Army

Hon. John McHugh

### Secretary of the Navy

Hon. Ray Mabus

### Secretary of the Air Force

Hon. Michael Donley

### Asst. Sec. of Defense (Acquisition)

Vacant

### DASD, Portfolio Systems Acquisition

Mr. Dave Ahern



### Director, Land Warfare & Munitions

Mr. Jose Gonzalez





# Excerpts from Secretary Gates January 6, 2011 Speech

- America is at war and confronts a range of future security threats, it's important not to repeat the mistakes of the past by making drastic and ill-conceived cuts to the overall defense budget.
- At the same time, it is imperative for this department to eliminate wasteful, excessive and unneeded spending, to do everything we can to make every defense dollar count.
- The goal was, and is, to sustain the U.S. military's size and strength over the long term by reinvesting those efficiency savings in force structure and other key combat capabilities.
- What is important is to have a budget baseline with a steady, sustainable and predictable rate of growth that avoids extreme peaks and valleys in defense spending that can be enormously harmful to readiness, planning and financial management.





# Mandate for Restoring Affordability and Productivity in Defense Spending (USD(AT&L) June 28, 2010 Memo)

- Deliver the warfighting capability we need for the dollars we have
- Get better buying power for warfighter and taxpayer
- Restore affordability to defense goods and services
- Improve defense industry productivity
- Remove government impediments to leanness
- Avoid program turbulence
- Maintain a vibrant and financially healthy defense industry

Obtain 2-3% net annual growth in warfighting capabilities without commensurate budget increase by identifying and eliminating unproductive or low-value-added overhead and transfer savings to warfighting capabilities. ***Do more without more.***



# Acquisition Efficiency Guidance Roadmaps

## Target Affordability and Control Cost Growth

- Mandate affordability as a requirement
- Implement “should cost” based management
- Eliminate redundancy within warfighter portfolios
- Achieve Stable and economical production rates
- Manage program timelines

## Incentivize Productivity & Innovation in Industry

- Reward contractors for successful supply chain and indirect expense management
- Increase Use of FPIF contract type
- Capitalize on progress payment structures
- Institute a superior supplier incentive program
- Reinvigorate industry’s independent research and development

## Promote Real Competition

- Emphasize competitive strategy at each program milestone
- Remove obstacles to competition
  - Allow reasonable time to bid
  - Require non-certified cost and pricing data on single offers
  - Enforce open system architectures and set rules for acquisition of technical data rights
- Increase small business role and opportunities

## Improve Tradecraft in Acquisition of Services

- Assign senior managers for acquisition of services
- Adopt uniform services market segmentation (taxonomy)
- Address causes of poor tradecraft
  - Define requirements and prevent creep
  - Conduct market research
- Increase small business participation

## Reduce Non-Productive Processes and Bureaucracy

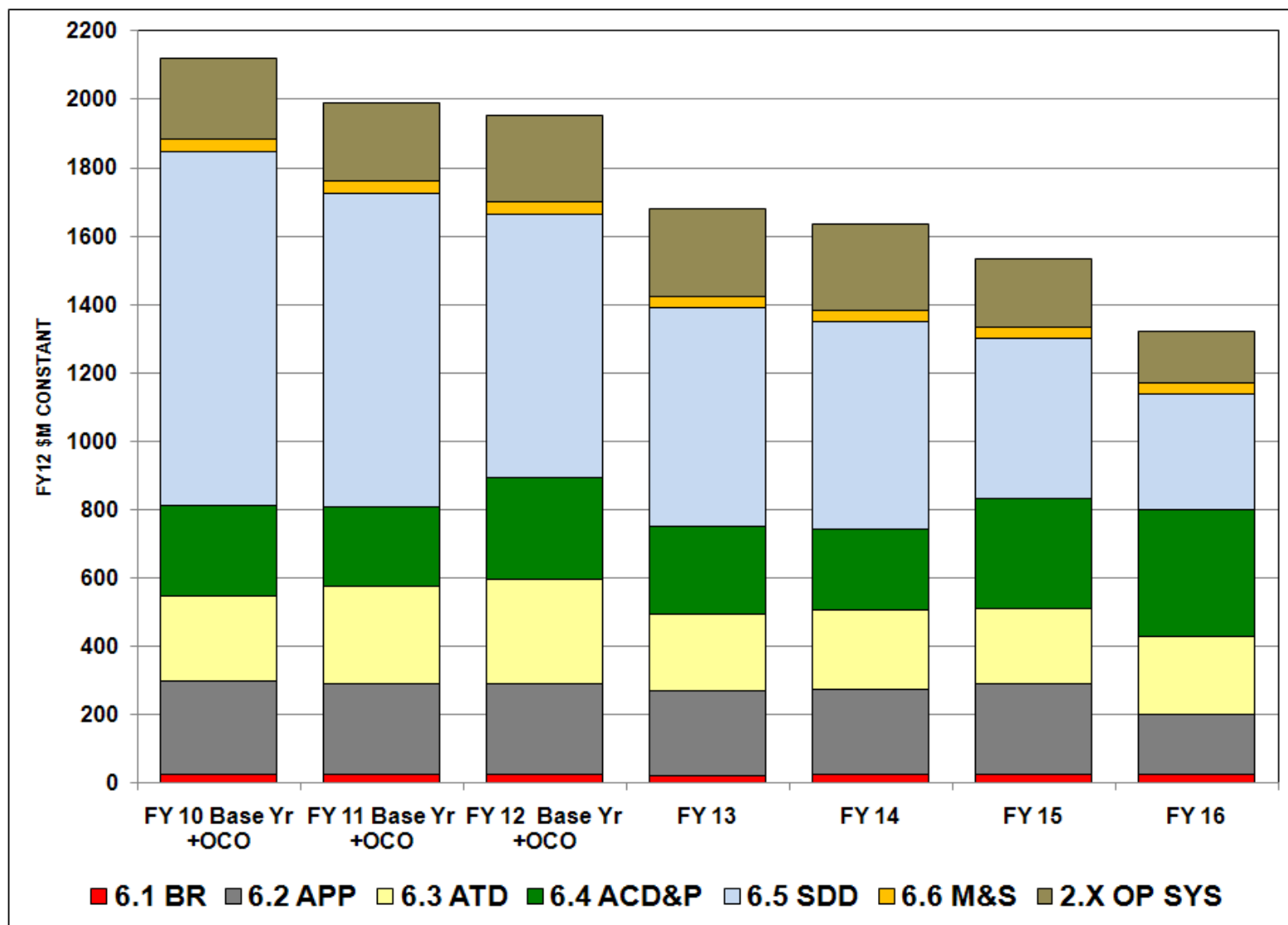
- Reduce frequency of OSD level reviews
- Work with Congress to eliminate low value added statutory requirements
- Reduce the volume and cost of Congressional Reports
- Reduce non-value added requirements imposed on industry
- Align DCMA and DCAA processes to ensure work is complementary
- Increase use of Forward Pricing Rate Recommendations (FPRRs) to reduce administrative costs



# Budget Overview

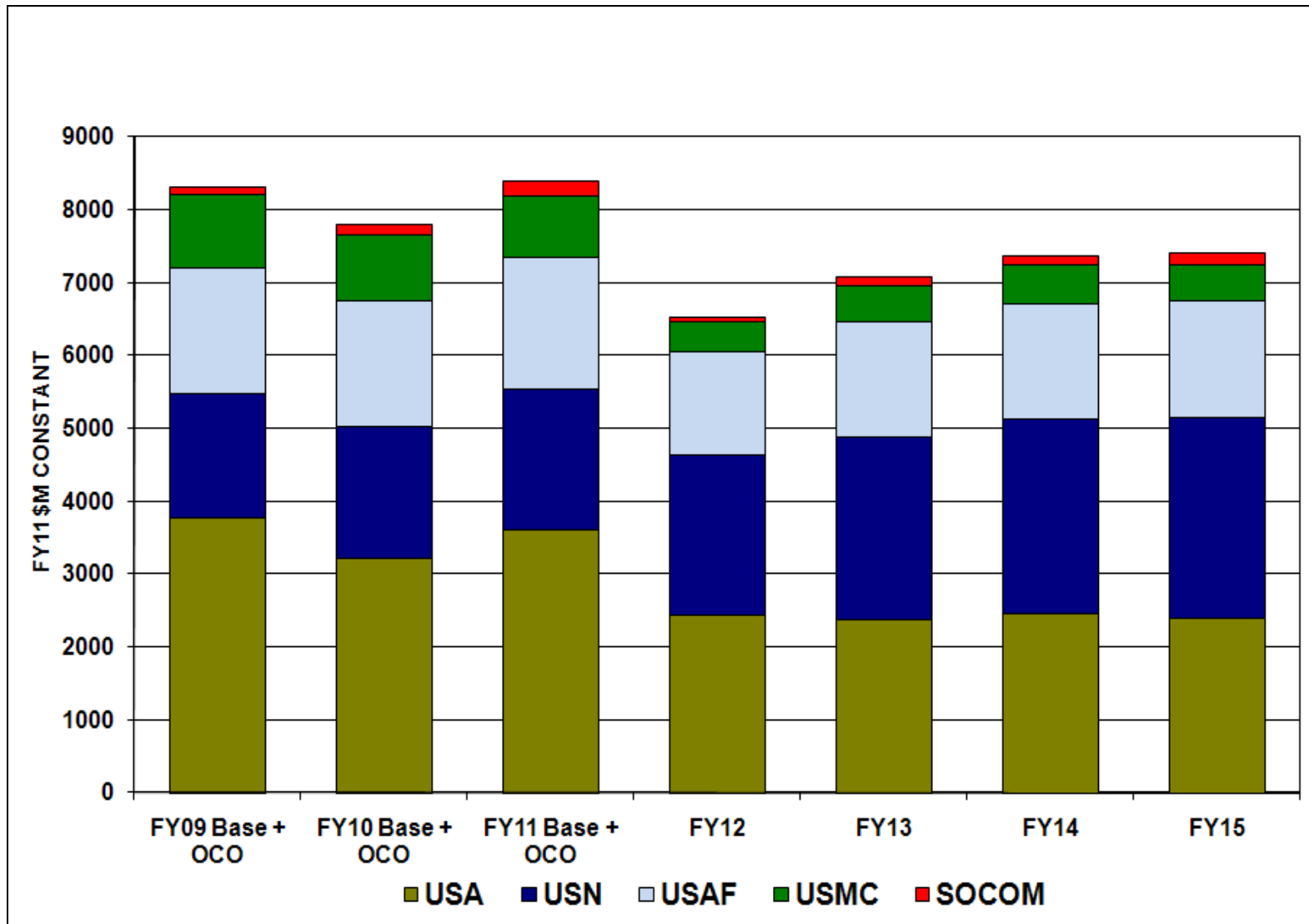


# Munitions RDT&E – PB12



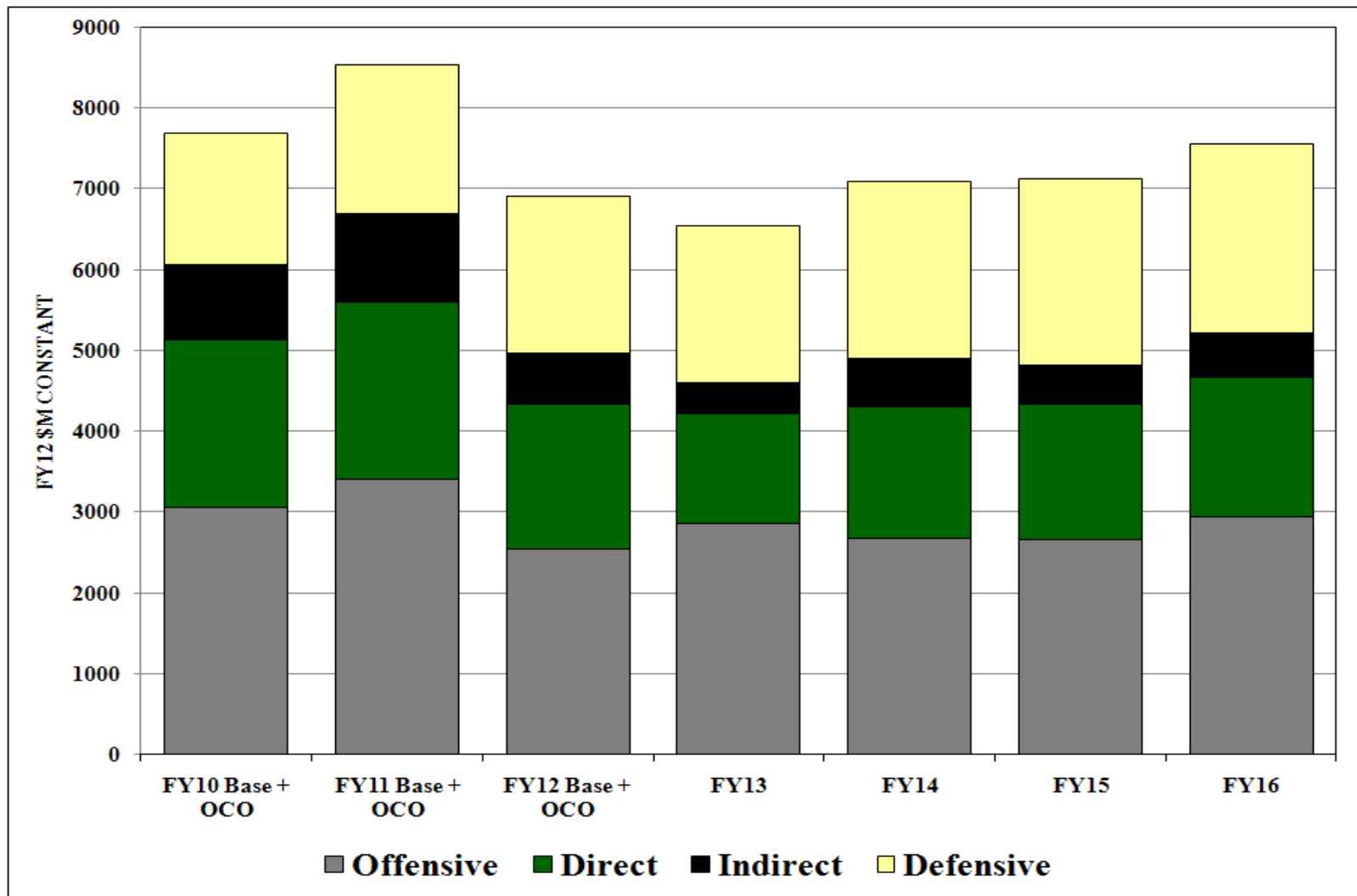


# Munitions Procurement – PB12





# Procurement by Type – PB12







# Department-level Fuze Initiatives



# DoD Fuze IPT Membership

- **OSD**
  - AT&L / Land Warfare & Munitions
  - AT&L / Defense Threat Reduction Agency
  - AT&L / Director of Defense Research & Engineering
  - AT&L / DCMA
  - Policy
- **Military Services**
  - Air Force
  - Army
  - Marines Corps
  - Navy
- **Department of Energy**
  - Lawrence Livermore National Laboratory
  - Los Alamos National Laboratory
  - Sandia National Laboratories



# Fuze IPT Strategic Plan

- **Fuze Industrial Base Strategic Plan**
  - **Goal #1:** Advance and maintain a healthy U.S. contractor base
  - **Goal #2:** Ensure that the Government develops and maintains the capability to execute its responsibility to assure the safety and suitability for service of fuze systems
- **Fuze Technology Base Strategic Plan**
  - **Goal #1:** Advance and maintain a healthy U.S. fuze technology base
  - **Goal #2:** Establish early and continued Government involvement in the development, application, and transition of fuze technology to munitions development



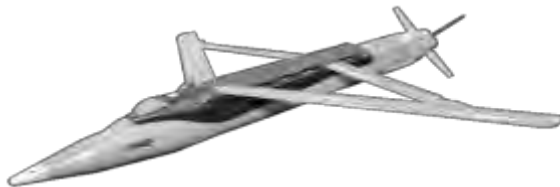
# Fuze IPT Issues/Focus

- **Current**
  - Monitor fuze acquisition programs
  - Identify and monitor fuze technology needs (JFTP)
  - Identify and monitor Industrial Base issues to include Single Point Failures
- **Revisit the Strategic Plan**
  - Hard look at Objectives needed to support existing Goals
  - Identify and prioritize actionable items that support Objectives
  - Coordinate with key Stakeholders in government and industry



# JFTP Overview

- Established program in FY 2010
  - High Reliability and Survivability were drivers
- 4 Fuze Area Technology Groups formed:
  - Hard Target Survivable Fuzing
  - Tailorable Effects Weapon Fuzing
  - High Reliability Fuzing
  - Enabling Technologies and Common Architecture
- Participants
  - DoD communities: S&T / Requirements / Acquisition
  - Dept. of Energy
  - **Industry via DOTC**





# DoD Ordnance Technology Consortium (DOTC)

## Government Laboratories



- OUSD (AT&L) LW&M
- Department of The Army
- Department of the Navy
- Department of the Air Force
- Department of Energy
- Special Operations Command
- Other Agencies and Departments

## Rapid & Agile Acquisitions



## National Warheads & Energetics Consortium

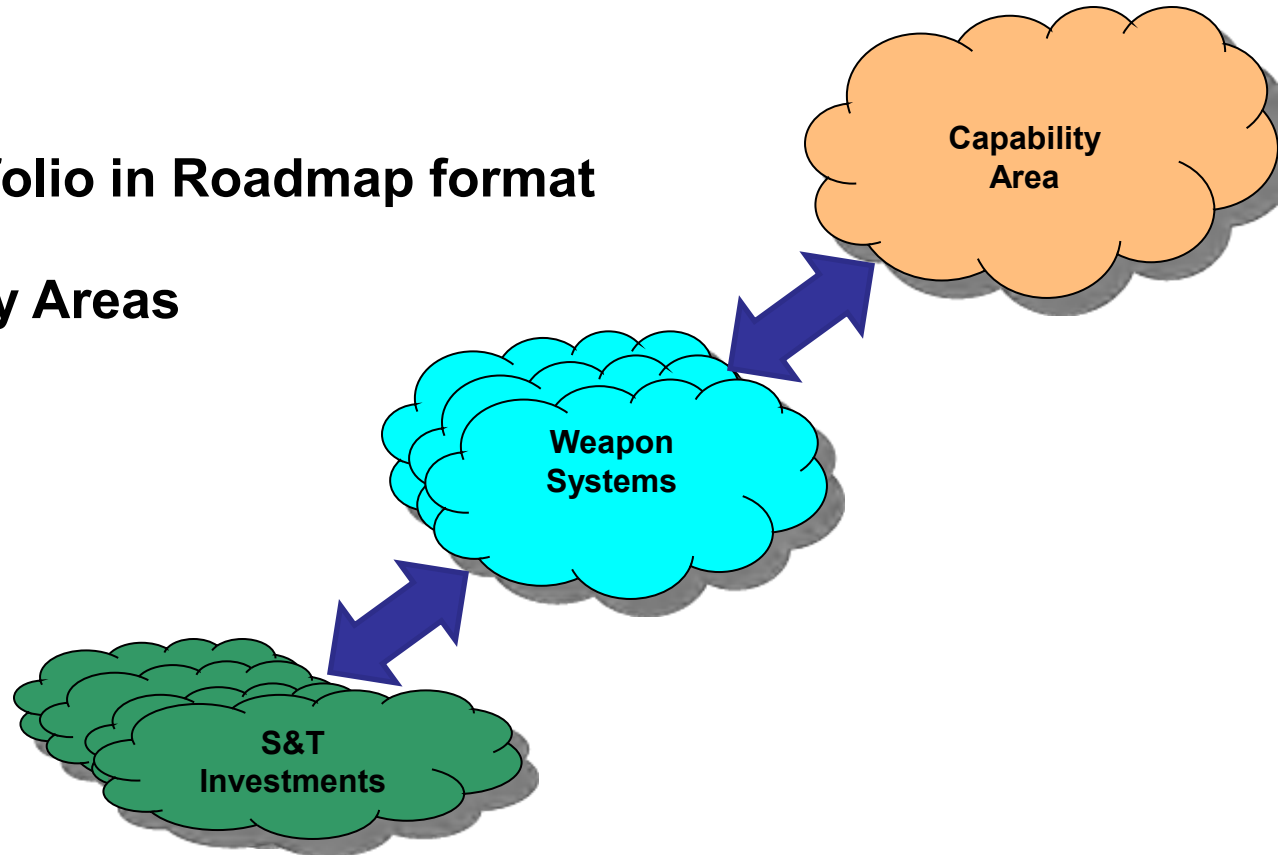


- Defense Contractors
- Traditional & Non-Traditional
- Academic Institutions
- Not-for-Profits Organizations

*DoD and NWEAC... Partnering to Leverage Capabilities and Investment*

# Weapon Portfolio Assessment

- ▶ **Layout Weapon Portfolio in Roadmap format**
  - ▶ **Identify Capability Areas**

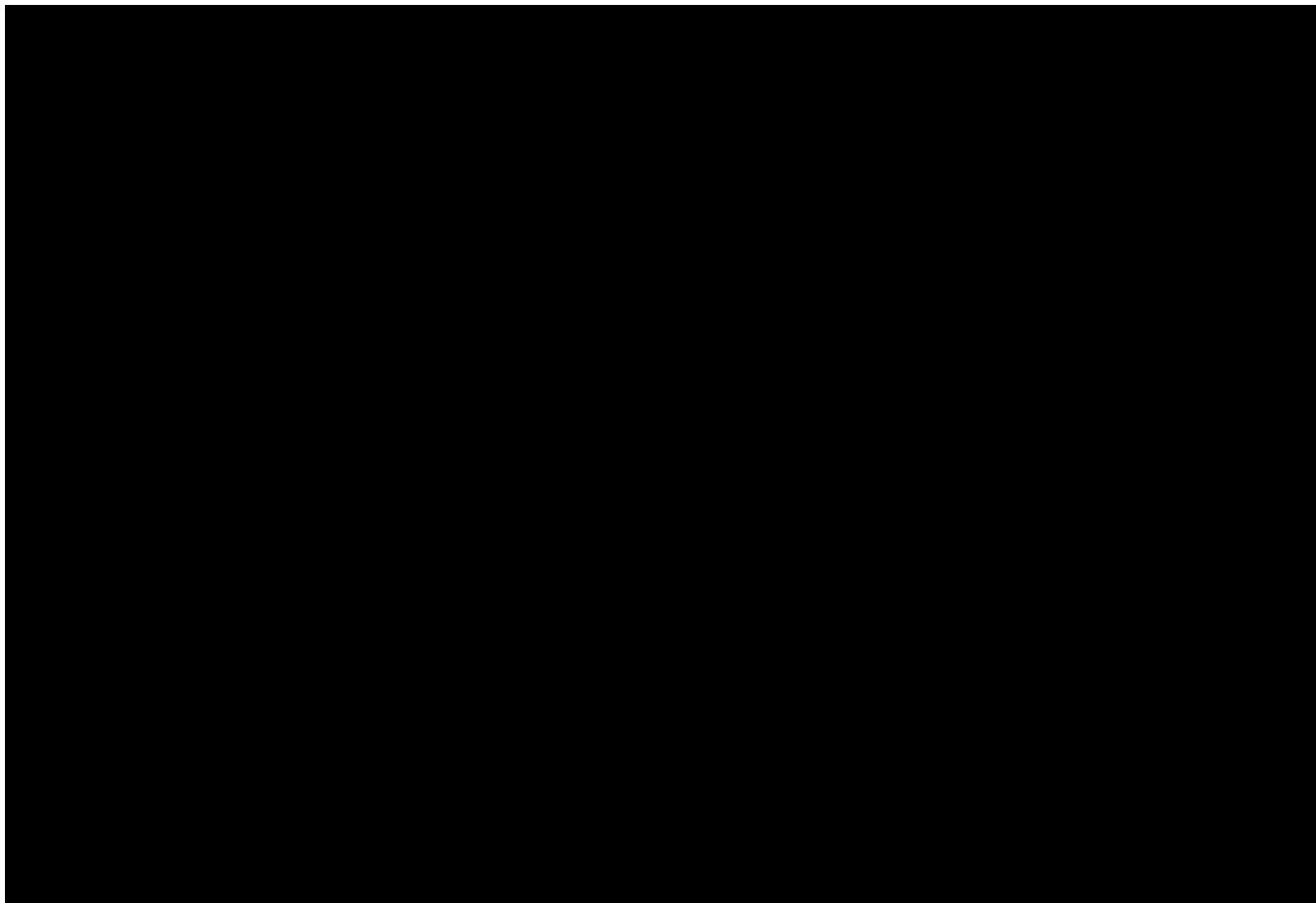


- ▶ **Identify current and future weapon systems**
- ▶ **Identify S&T investments that support upgraded and new weapon systems.**
- ▶ **Assess the portfolio (Effectiveness and Affordability)**





Questions?



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**IRONHORSE**





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***IRONHORSE***



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***IRONHORSE***



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**IRONHORSE**





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# FUZE AND INITIATION SYSTEMS TECHNICAL REVIEW PANEL

THE NDIA'S 55<sup>TH</sup> ANNUAL FUZE CONFERENCE  
SALT LAKE CITY, UT  
24 - 26 MAY 2011

Gabriel Soto  
Fuze and Warheads Division (478000D)  
Naval Air Warfare Center Weapons Division, China Lake CA  
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[gabriel.soto@navy.mil](mailto:gabriel.soto@navy.mil)

# Outline

- ▣ Background
- ▣ Purpose
- ▣ Membership
- ▣ Interface
- ▣ Design Safety Criteria
- ▣ Review Process
- ▣ Presentation/Data Package
- ▣ Recent Focus Areas
- ▣ Observations

# HISTORY



# USS Oriskany

- ▣ October 26, 1966
  - Magnesium parachute flare exploded in the flare locker of Hanger Bay 1, beneath the carrier's flight deck
  - A seaman threw the ignited flare back into the weapons locker where the flares were kept for storage instead of throwing it over the side into the water
  - Fire raced through five decks
  - Crewmen jettisoned heavy bombs which lay within reach of the flames, wheeled planes out of danger, and rescued pilots
- ▣ 44 killed
- ▣ 6 aircraft destroyed



# USS Forrestal

- ▣ July 29, 1967
  - A ZUNI rocket was fired accidentally from an aircraft
  - 2 different teams bypassed a safety thinking the other safety would still provide the safety
  - The rocket screamed across the deck, struck the future Sen. John McCain's plane and ignited a fuel fire (3 months later he was shot down over Hanoi was a POW for 6 yrs)
  - 90 seconds after the fire started, a 1,000 lb bomb detonated
  - The detonation ruptured the flight deck, and burning fuel spilled into the lower levels of the ship
  - Bombs, warheads, and rocket motors exploded from the intensity of the fire
- ▣ 134 killed
- ▣ 161 wounded
- ▣ 21 aircraft destroyed





# USS Enterprise

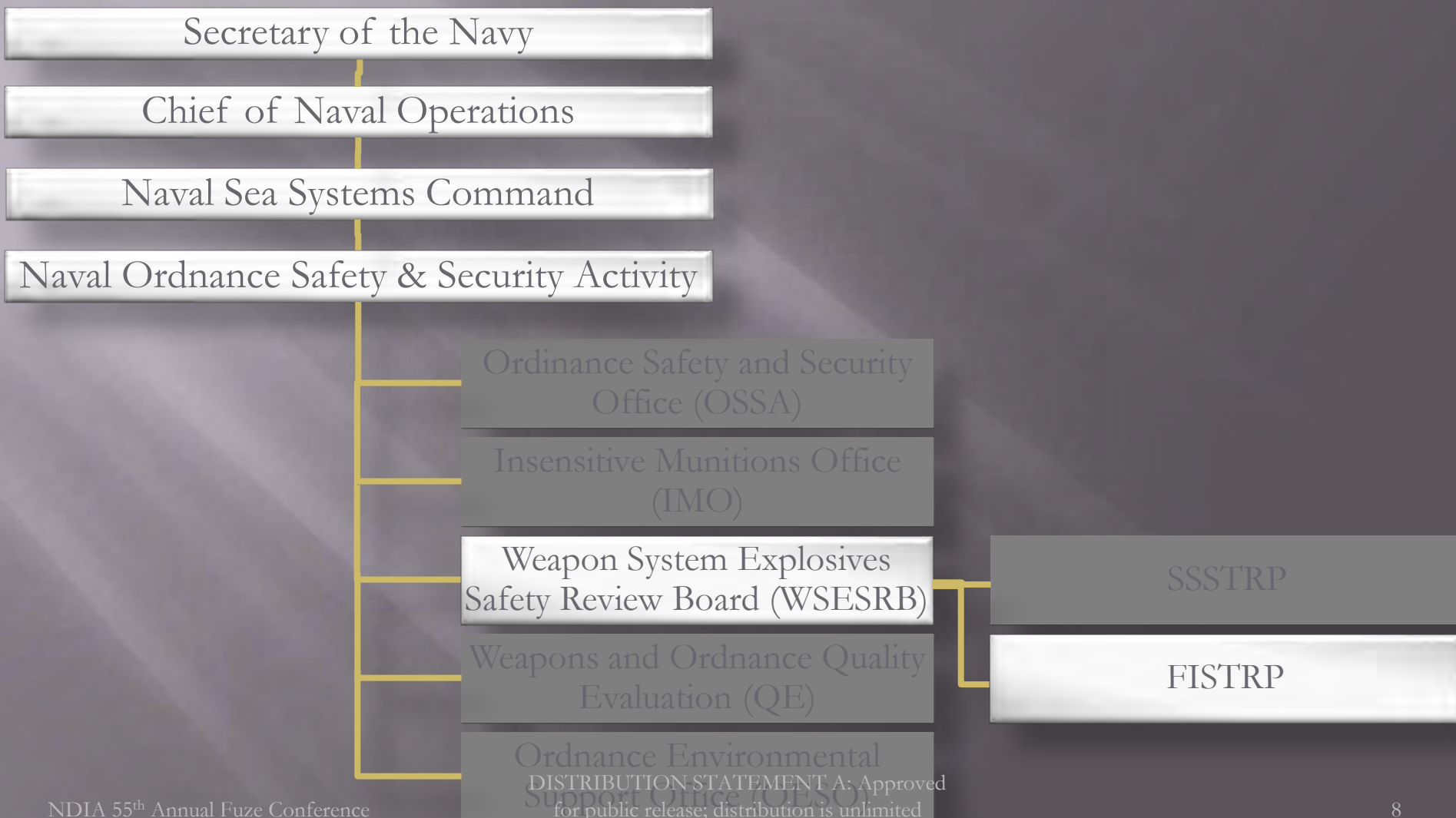
- ▣ January 14, 1969
  - Exhaust from an aircraft engine starter was directed at a pod containing 4 ZUNI rockets. Heat caused a warhead to detonate. Fragments ruptured the aircraft's fuel tank and ignited a fire.
  - Three more ZUNI warheads detonated less than a minute after the first explosion. The shaped charges blew holes through the flight deck allowing burning fuel to invade the lower decks.
- ▣ 28 killed
- ▣ 344 wounded
- ▣ 15 aircraft destroyed



# Safety Program

- ▣ As a result of these accidents, a comprehensive ordnance safety program was initiated
  - Insensitive Munitions (IM)
    - ▣ Fast cook-off
    - ▣ Slow cook-off
    - ▣ Bullet impact
  - HERO
  - Environmental Testing
    - ▣ MIL-STD-331
  - Design Safety
    - ▣ MIL-STD-1316, MIL-STD-1901

# Navy Safety Board Organization Chart



# Technical Review Panels

- ▣ Weapon Systems Explosive Safety Review Board (WSESRB) established Technical Review Panels (TRPs) in late 1980's
  - WSESRB chairperson may establish TRPs to review specific safety aspects requiring special expertise
  - Regularly meeting TRPs currently consist of:
    - ▣ Software System Safety Technical Review Panel (SSSTRP)
      - SSSTRP reviews specific safety aspects requiring special expertise in the area of analysis and testing of safety-critical software, firmware, and software-like devices contained in weapons and weapon systems
    - ▣ Fuze and Initiation Systems Technical Review Panel (FISTRP)
      - FISTRP reviews specific safety aspects requiring expertise in the area of design, analysis, and testing of fuzes, safety and arming (S&A) devices, initiation safety devices, and initiators



# Purpose

- ▣ Provide expert technical review of the safety programs for fuze designs, ignition safety devices, and related S&A devices used in Navy weapon systems (Ref. NAVSEAINST 8020.6)
  - Allows more in-depth review
  - Affords focused review by technical experts in specialized fields
  - Reduces time required at WSESRB review

# FISTRP Membership

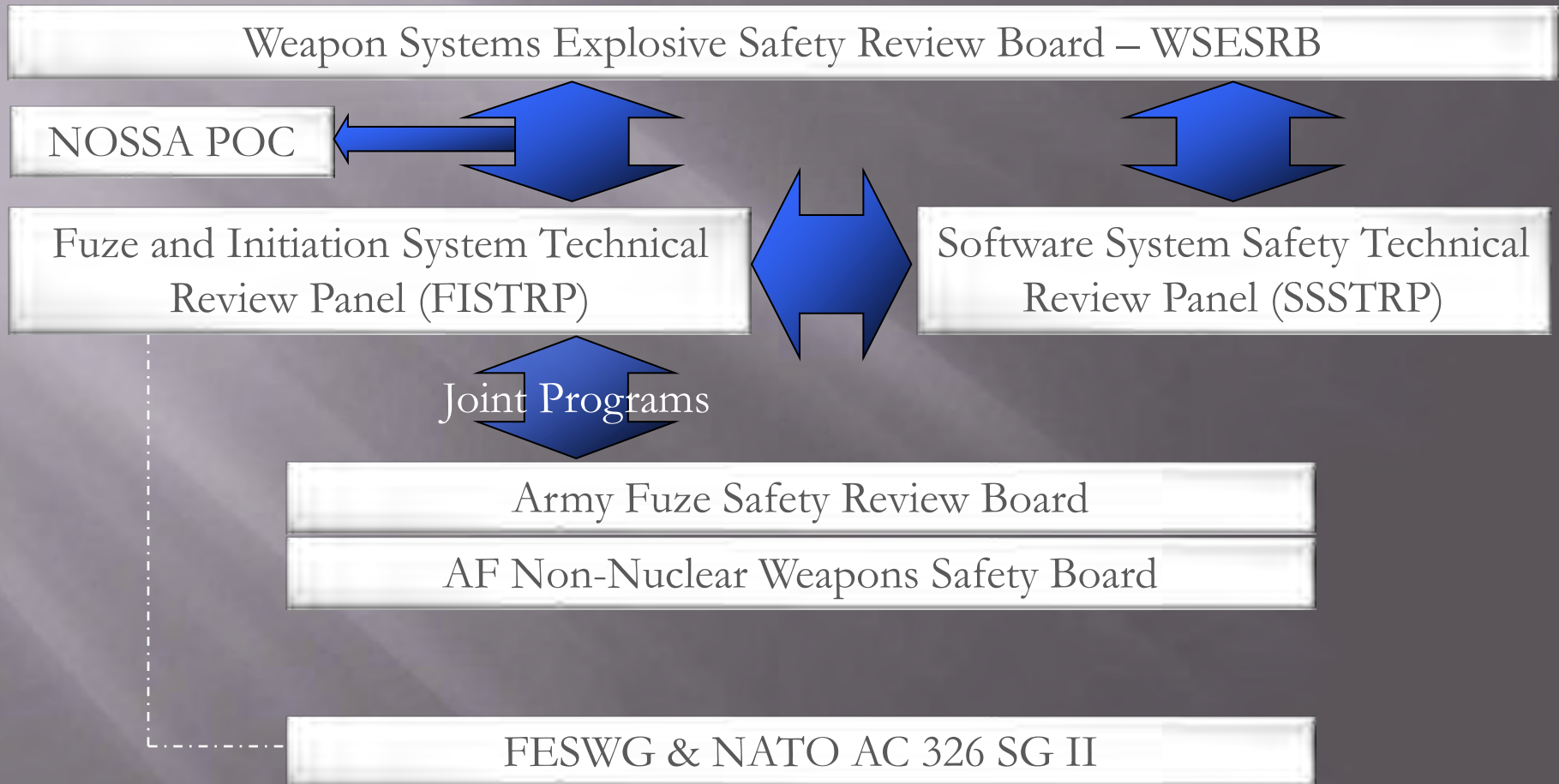
- ▣ Chairperson appointed by the WSESRB chairperson
- ▣ Members and technical advisors appointed by TRP chairperson
  - Members are typically government employees from Navy Labs
  - Individuals must have experience and expertise in their respective areas
    - ▣ Specific areas of expertise include the following:
      - Fuze design, ignition system and ignition safety device design, explosive safety, initiators, logic devices, system safety, fuze development, and individual weapon systems design and development
  - Members are approved by WSESRB
- ▣ Individuals from the Air Force and Army safety boards may participate



# 2011 FISTRP MEMBERS

- ▣ Raymond Ash - Naval Air Warfare Center Weapons Division China Lake
- ▣ Ralph Balestrieri - Naval Surface Warfare Center Indian Head Division
- ▣ Tinya Coles-Cieply - Naval Surface Warfare Center Indian Head Division
- ▣ Randall Cope - Naval Air Warfare Center Weapons Division China Lake
- ▣ Michael Demmick - Naval Ordnance Safety and Security Activity
- ▣ Bradley Hanna - Naval Surface Warfare Center Dahlgren Division
- ▣ John Hendershot - Naval Surface Warfare Center Indian Head Division
- ▣ George Hennings - Naval Air Warfare Center Weapons Division China Lake
- ▣ John Hughes - Naval Air Warfare Center Weapons Division China Lake
- ▣ John Kandell - Naval Air Warfare Center Weapons Division China Lake
- ▣ David Libbon - Naval Surface Warfare Center Dahlgren Division
- ▣ Melissa Milani – EODTECHDIV Indian Head Division
- ▣ Scott Pomeroy - Naval Surface Warfare Center Dahlgren Division
- ▣ Gabriel Soto - Naval Air Warfare Center Weapons Division China Lake

# FISTRP Interfaces



# Review Criteria

## ▣ Design Safety Criteria

- Fuzes/S&As STANAG 4187/MIL-STD-1316
- Initiation Systems STANAG 4368/MIL-STD-1901
- Hand Emplaced Ord. STANAG 4497/MIL-STD-1911
- Initiators STANAG 4560/MIL-DTL-23659
- Explosive Materials STANAG 4170/AOP-7
- Safety & Suitability STANAG 4157/AOP-20/MIL-STD-331
- WSESRB Technical Manual on Electronic Safety and Arming Devices with Non-interrupted Explosive Trains

# Review Criteria (continued)

- ▣ Design Safety Criteria (continued)
  - FESWG Technical Manuals on Logic Devices
  - FESWG Guideline for Qualification of Fuzes, S&As and ISDs (Draft)
  - Proposed Methodology for Electrical Stress Testing (EST) of Electronic Safe Arm Devices (Draft)
- ▣ Designs will be assessed against most current version



# Review Process

- ▣ Program coordinates with NOSSA POC and FISTRP chairperson to determine appropriate type of review
  - Formal Review
    - ▣ Data package is required 21 days prior to review
    - ▣ Typical review will consist of no more than four to six hours of review/discussions and two or more hours for panel members to caucus
    - ▣ Draft findings will be briefed to the program at the conclusion of review
      - Findings are not final until presented to and accepted by the WSESRB
      - Findings are formally briefed to WSESRB at Executive Session
    - ▣ The agenda will be left to the discretion of the program office; however, it should take into consideration the above and should address the items listed in the Technical Data Package section below.
  - Letter Data Package
    - ▣ Requires limited review of data
    - ▣ Involves narrowly focused issue
  - Technical Assistance Meeting
    - ▣ Can be a specific device or concept
    - ▣ No findings or minutes generated

# Data Package and Presentation Material

- ▣ Brief program and/or weapon system overview
- ▣ Identification of the specific application, platform, and/or weapon for which approval is being requested
- ▣ Design description including:
  - Detailed description of arming environment/user interactions
  - Detailed description of safety feature implementations to include mechanical drawings and/or electrical schematics
  - Identification of all energy sources, including stored energy devices, in the system
  - Identification of all energetic materials in the design and the qualification status of each
  - Identification of application unique hazards
- ▣ Design validation and qualification test program
  - Detailed description of the life cycle and life cycle environments to which the device is exposed throughout its service life
  - MIL-STD-331 qualification plan/report including number of units, sequence of tests, test parameters, pass-fail criteria, and justification of test selection
  - Comparison of qualification testing to “DoD Fuze Engineering Standardization Working Group Guideline for Qualification of Fuzes, Safe and Arm Devices and Ignition Safety Devices”
  - Justification of ‘by similarity’ claims



# Data Package and Presentation Material

- Initiator Qualification Test Program, where appropriate
  - MIL-DTL-23659 Qualification plan/report
  - Justification of 'by similarity' claims
- Fault Tree Analysis including:
  - Failure modes, effects, and criticality analysis
  - Description of fault tree analysis process and underline assumptions
  - Description of minimum cut sets and causal factors
  - Independent assessment of fault tree analysis
- Assessment of the design to applicable safety standards such as MIL-STD-1316D, MIL-STD-1901, MIL-STD-1911, WSESRB Technical Manual, and other safety criteria to include:
  - Compliance matrices
  - Supporting documentation
  - For any areas of non compliance, quantification and acceptance of risk at the appropriate level
- Safe Separation/Arming Delay Analysis, where applicable
  - Joint Munitions Effectiveness Manual, or equivalent, safe separation analysis which includes effects of warhead blast, heat and fragmentation. Analysis should also include the effect of weapon parasitic and any unspent energetic
  - Identify any operational requirements which mandate early arming – arming where the probability of hit is less than one in 10,000 or probability of hazardous fragment (for human body damage) is less than one in 10,000 - and quantify the hazard to the user
- Draft presentation

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for public release; distribution is unlimited

# Compliance with Requirements

- ▣ Compliant
  - Meet the requirement
  - Meet the intent of the requirement (as interpreted by the FISTRP)
- ▣ Non-Compliant
  - Seek risk acceptance in accordance with MIL-STD-882
    - ▣ The hazard associated with a non-compliance must be determined
    - ▣ The risk associated with this hazard must be quantified
    - ▣ Mitigations should be considered
    - ▣ The residual risk must be accepted at the appropriate level

# Closing Findings

- ▣ Submit a Letter Data Package (LDP) through your NOSSA POC
  - Provide justification
- ▣ Request closure during a formal review
  - Present justification
- ▣ Finding are not closed at informal reviews

# RECENT TECHNICAL TOPICS

# Logic Devices

- ▣ Important updates concerning charge-based memory device usage
  - Evolving Requirements for the Use of Logic Devices in the Implementation of Safety Features
    - ▣ Mr. John Hughes
- ▣ Use of microprocessors/microcontrollers



# Acceptable In-Line Energetics

- ▣ Only those energetics listed in the appropriate standard are approved for use in a position leading to the initiation of the main energetic without interruption
- ▣ Other materials must be tested in accordance with AOP-7 and shown to be no more sensitive than RDX type I or II, class 5 conforming to MIL-DTL-398 (RDX or BKNO<sub>3</sub> for pyrotechnic energetics)
  - Requires testing reference material contemporaneously with the candidate material
  - Must pass all mandatory AOP-7 requirements

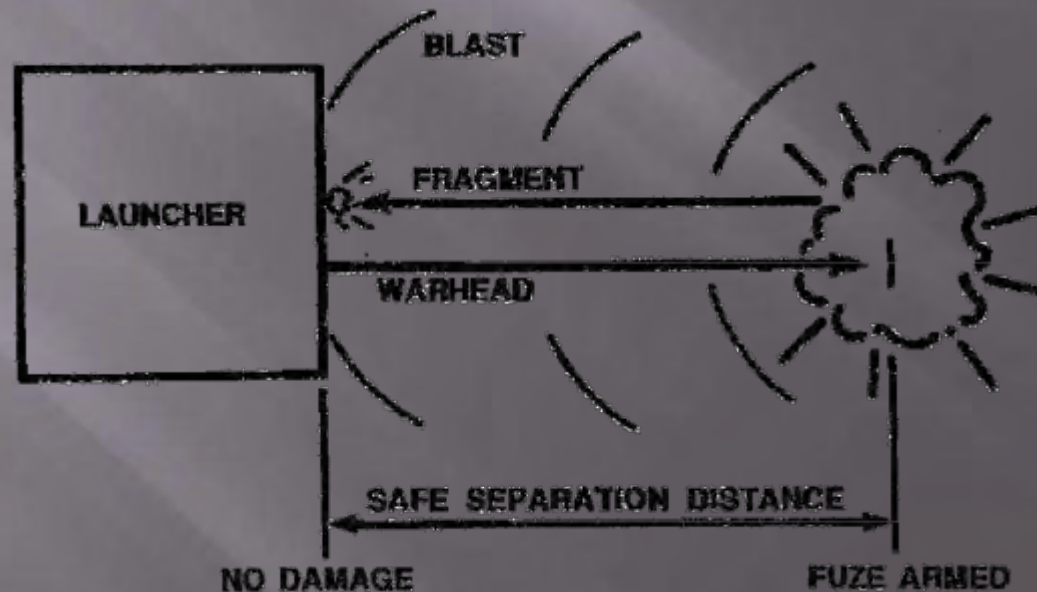


# Use of In-Line Initiators

- ▣ New or Modified Initiator
  - MIL-DTL-23659 qualification test series
    - ▣ ILIs not fully tested to MIL-DTL-23659 may be acceptable for a particular application, but will not be MIL-DTL-23659 qualified and will need to show a non-compliance in the applicable MIL-STD
  - Safety fireset testing
  - Must use energetics qualified and approved for in-line use
- ▣ Previously Qualified Initiator
  - Consider environments not covered in previous qualification
    - ▣ Electrical cook-off testing
    - ▣ Environmental exposure
  - Firing properties with intended use fireset
    - ▣ Transient electrical characteristics 25% rule
  - High fire testing

# Safe Separation Distance

- ▣ The minimum distance between the launcher and the munition beyond which the hazards to the delivery system and personnel resulting from the functioning of the munition are reduced to an acceptable level



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for public release; distribution is unlimited

# Safe Separation Analysis

## ▣ MIL-HDBK-504

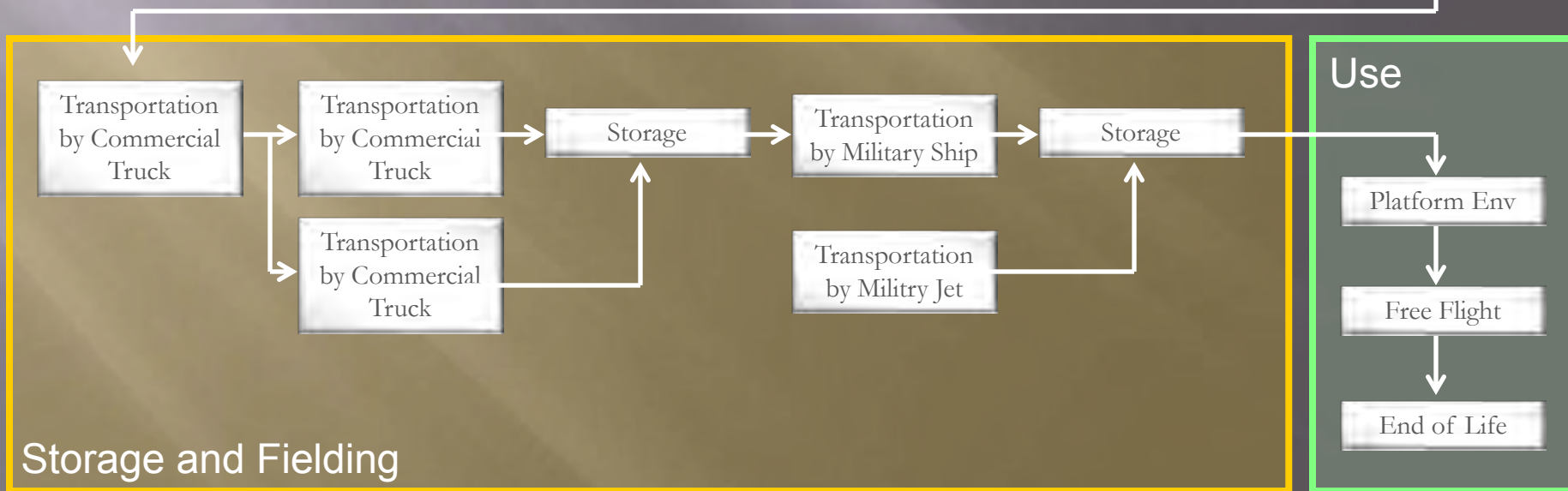
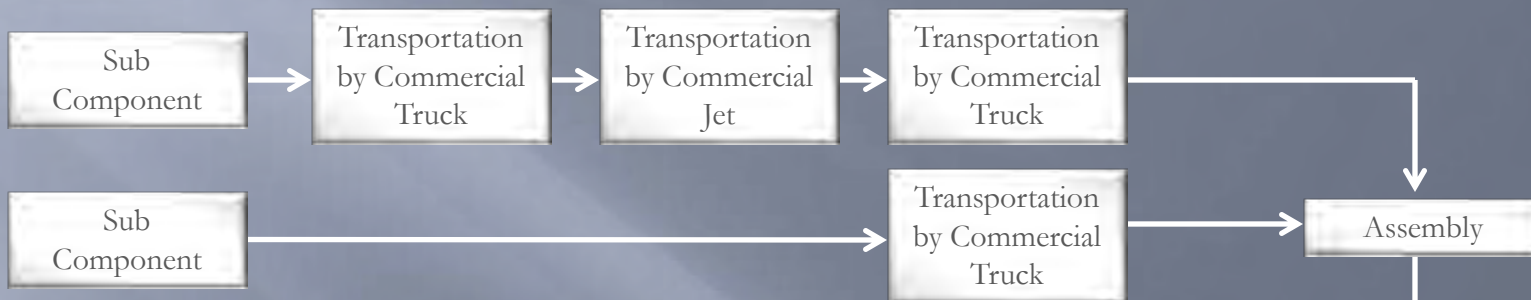
- Assumes function/detonation at minimum arming distance
- $< 1$  in 10,000
  - ▣ Probability of Hit for launch platform (MIL-HDBK-504, appendix B)
  - ▣ Probability of hazardous fragment for personnel (MIL-HDBK-504, appendix A)
- $> 1$  in 10,000 must seek risk acceptance
  - ▣ Residual risk  $< 1$  in 1,000,000 for a 1E Hazard
    - Probability of function limited to 1 in 100
    - Probability of kill
    - Probability of lethal fragment

# Fuze Qualification Testing

- ▣ MIL-STD-331C Environmental and Performance Tests for Fuze and Fuze Components Mechanical Shock Tests
  - Jolt - safe for use
  - Jumble - safe for use
  - 40 ft (12 m) drop - safe for disposal
  - 5 ft (1.5 m) drop - safe for use
  - Transportation Vibration
- ▣ Vibration/Climatic Tests – Operable
  - Thermal Shock
  - Long Term Storage @ -65°F / +160°F
  - Rough Handling
  - Salt Fog
  - Rain
  - Dust
- ▣ Safety, Arming and Functioning Tests
- ▣ Fuze Exposure to Physical Conditions During Complete Life Cycle

# Example of Life Cycle Environments

## Manufacture



## Use



## Storage and Fielding



# Review Tips

- ▣ Refresh our memory
  - Formal, informal, LDP
- ▣ Fuze/initiation system safety requirements can impact design; early start is essential to minimize this potential
- ▣ Advancement in technology often stresses safety assessment ability
- ▣ General requirements continuously being clarified for specific technology
- ▣ Keeping safety architecture and implementation simple is generally a good thing
- ▣ Misinterpretation of safety requirements
- ▣ Comprehensive testing is essential part of safety assessment





# **MK419 Mod 1 Multi-Function Fuze Product Improvement Program**

BY

Richard Chapman  
Naval Surface Warfare Center  
Dahlgren Division

# OUTLINE

- **PERFORMANCE:**

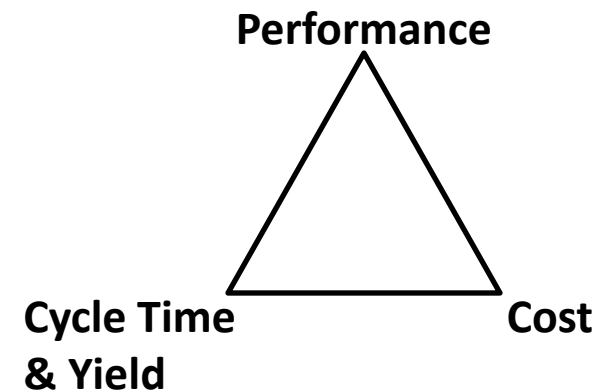
Multi-Function Fuze (MFF) Operational Modes

- **CYCLE TIME & YIELD:**

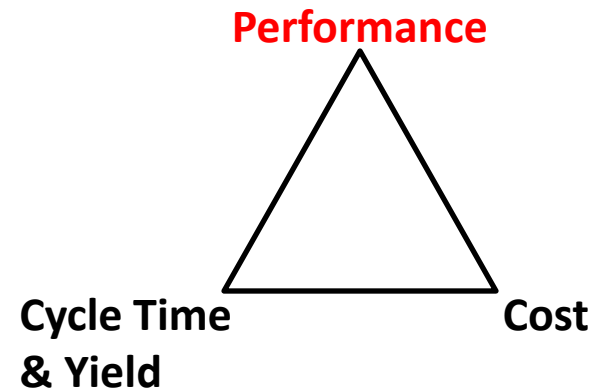
Statistical Process Control Handshake for Cycle Time and Yield

- **MOD 1 COMPONENT SUMMARY:**

Performance, Cycle Time, Yield, and Cost with Full Module Assembly



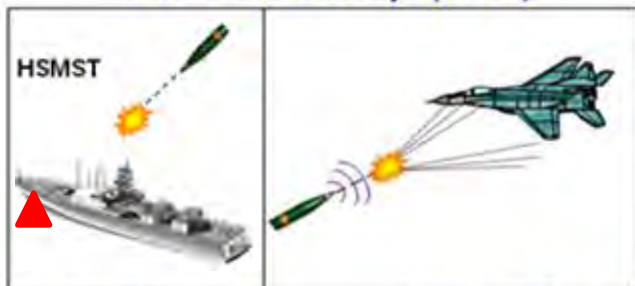
# PERFORMANCE: Multi-Function Fuze (MFF) Operational Modes



# Multi-Function Fuze (MFF)

## Operational Modes

**Air Proximity (AIR)**



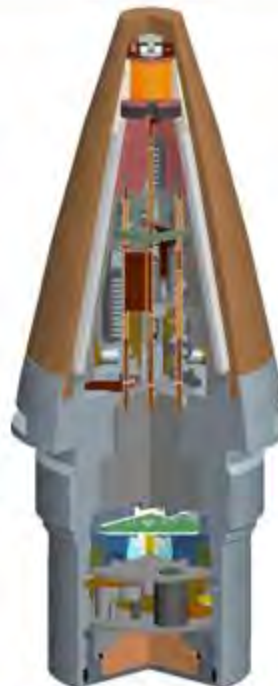
**Point Detonating (PD)**



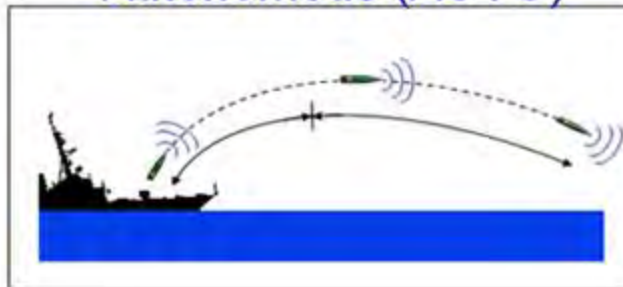
**Surface Proximity (HOB)**



**Electronic Time (ET)**



**Autonomous (AUTO)**



Replaces VT, CVT,  
MT and PD fuzes  
on HE rounds.  
Simplifies logistics.  
Uses IM Explosives.

Multiplies effectiveness  
of ship's magazine.  
Improves fuze  
performance, accuracy  
and versatility.

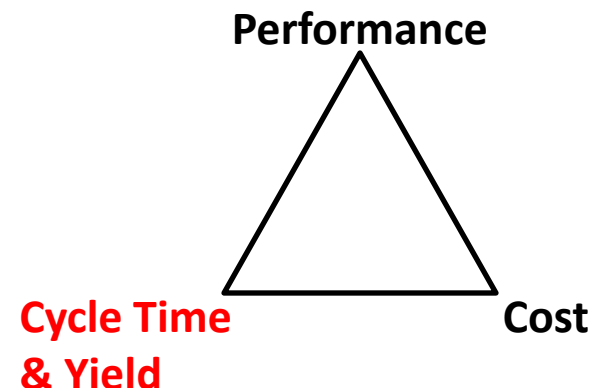
**The MFF can fit 76mm and 5 inch rounds.**

# **CYCLE TIME & YIELD:**

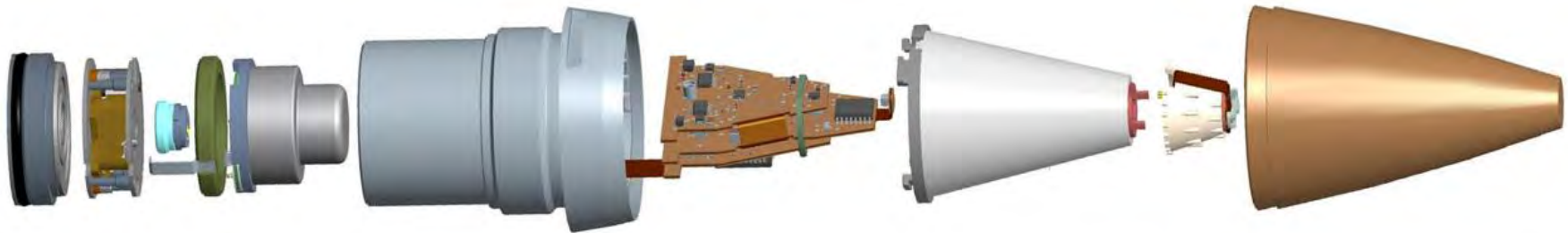
## **Statistical Process Control**

### **Handshake**

### **for Cycle Time and Yield**



# Statistical Process Control For Cycle Time Reduction



Mechanical Count Summary	MOD-0	MOD-1
Circuit Boards & Interconnect Flexes	6	3
Lap Solder Joints	16	0
Other Hand Soldered Connections	12	6
Custom Shimming Operations	1	0
Mechanical Parts*	37	31

*\* CCAs and purchased assemblies (Booster, S&A, Det, etc.) are considered a single mechanical part*

## Mod 1 Cycle Time is reduced by 65%

Decreased Mechanical Part Count Simplifies Assembly (Reduces Cycle Time) And Improves Yield



# Statistical Process Control For Yield

- **Initial Review of Product Parameters**

- FMEA Design
- Technical Data Package

- **Determine Process Capability**

- FMEA Manufacturing
- Determine process capability
  - $C_p = (USL - LSL) / (6 * \text{Sigma})$
  - $C_{pl} = (\text{Mean} - LSL) / (3 * \text{Sigma})$
  - $C_{pu} = (USL - \text{Mean}) / (3 * \text{Sigma})$
  - $C_{pk} = \text{Min}(C_{pl}, C_{pu})$

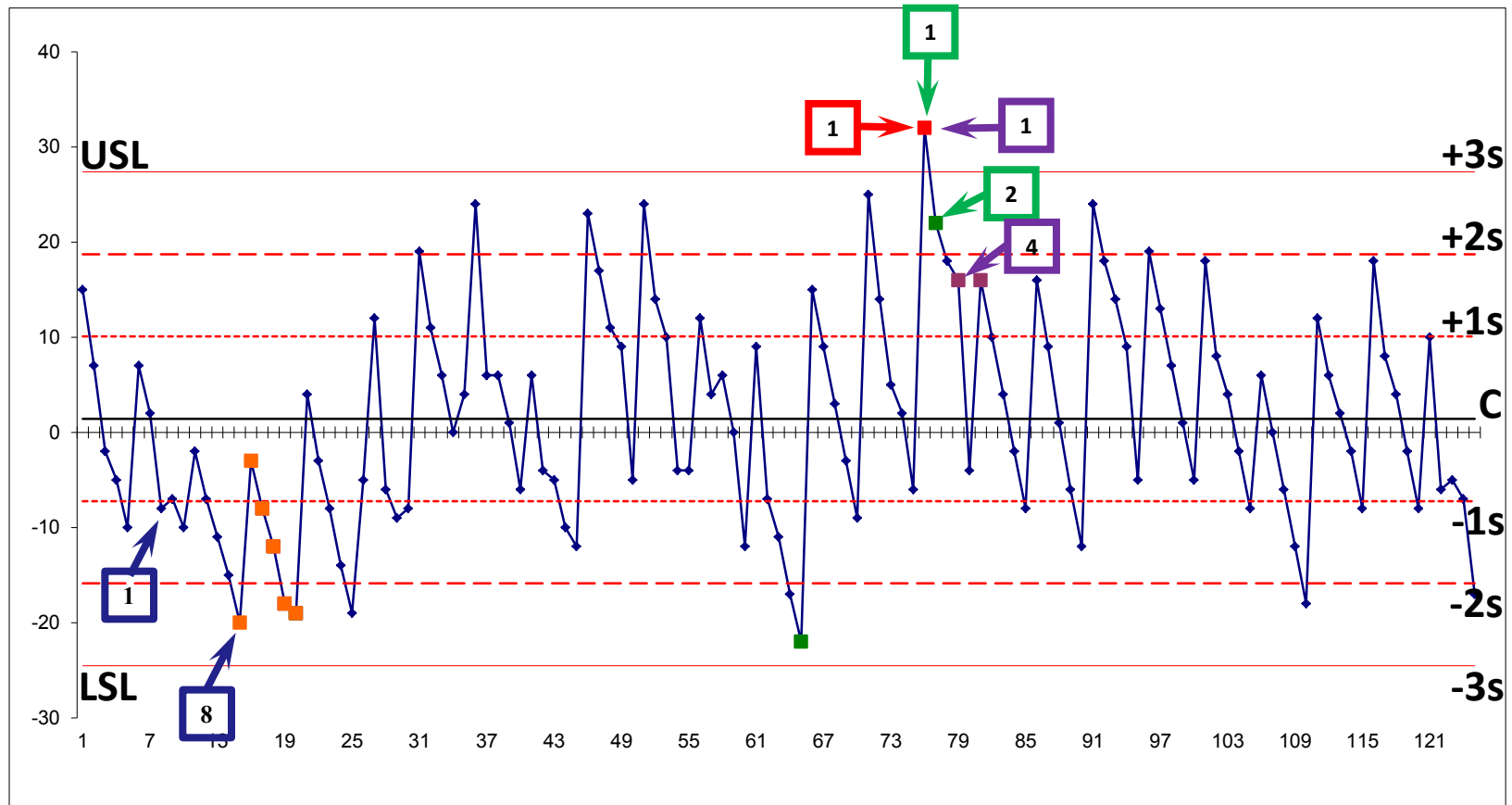


**CENTER TARGET**  
+  
**SMALL SIGMA**  
+  
**WIDE USL – LSL**  
=

**EXCELLENT YIELD**

**GOOD CAPABILITY**

# X Bar & S Statistical Process Control Shewhart Rules (Yield Consequence)



— **Three** Sigma Limit  
 - - - **Two** Sigma Limit  
 . . . **One** Sigma Limit  
 — **Average**

— **A single point** outside the **three** sigma limit  
 — **Two of three pts** outside the **two** sigma limit  
 — **Four of Five pts** outside the **one** sigma limit  
 — **Eight** in a row on the same side of centerline

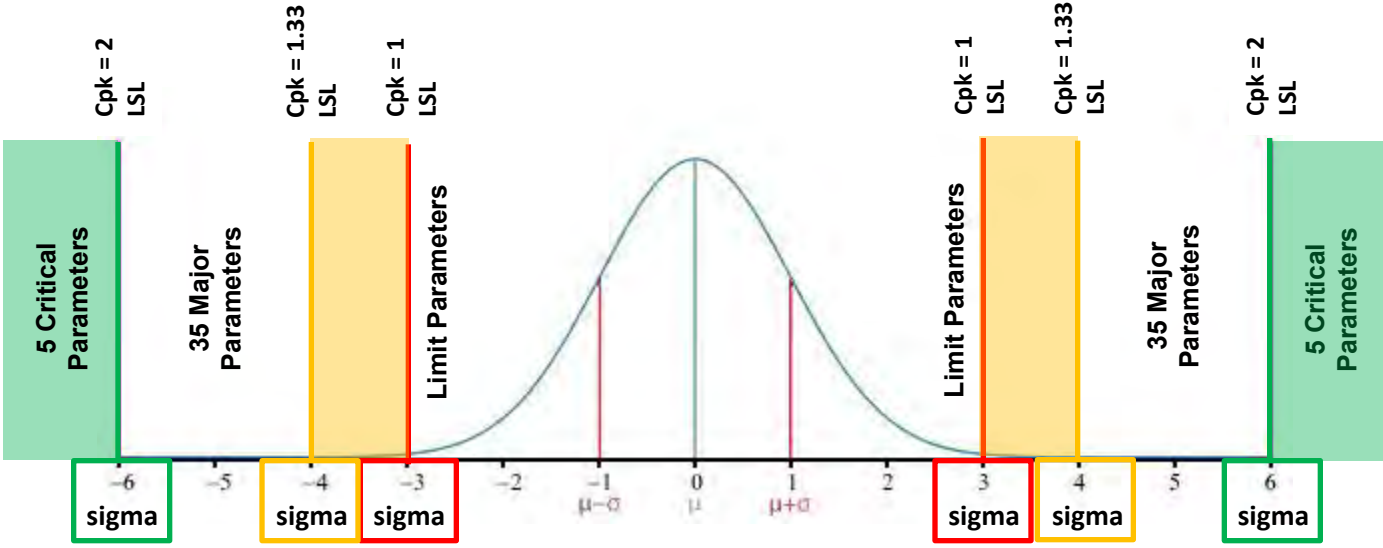
# Statistical Process Control

## Cycle Time and Yield Handshake

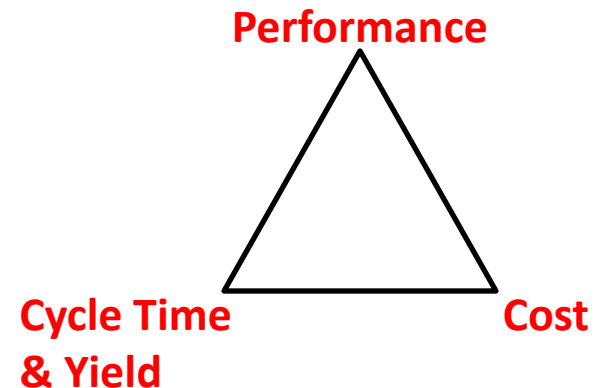
Fewer steps not only reduce Cycle Time, but increases Yield due to reduced manipulative errors.

Spec Limit	Centered Yield (One Step)	Percent Yield (89 Steps)
1s > USL, LSL	68.27%	0.00%
2s > USL, LSL	95.45%	1.59%
3s > USL, LSL	99.73%	78.62%
4s > USL, LSL	99.99%	99.44%
5s > USL, LSL	100.00%	99.99%
6s > USL, LSL	100.00%	100.00%

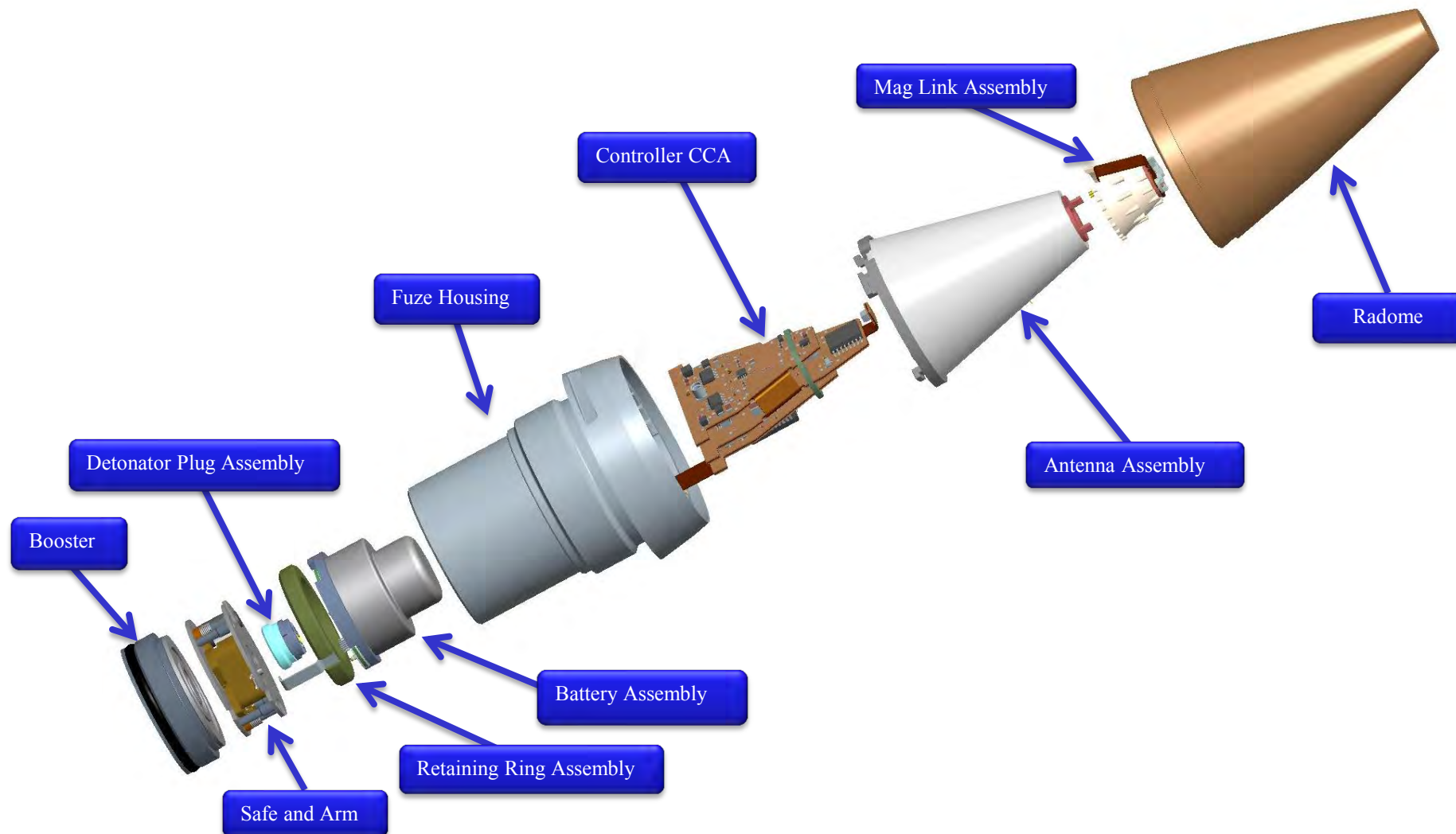
95% Fuze Yield



# **MOD 1 COMPONENT SUMMARY: Performance, Cycle Time, Yield, and Cost with Full Module Assembly**




# Major Subassemblies And Components



# Radome And Mag Link Assembly

## IMPROVEMENTS FOR MOD 1

- **Performance:**  
N/A
- **Cycle Time:**  
Simplified assembly
- **Yield:**  
Automation increases yield  
Cpk increase
- **Cost:**  
Component cost reduction

MOD-1	
✓ No change – No risk	
✓ Eliminated individual tuning costs	
✓ Automated reflow soldering process	
✓ Small, low cost capacitors	
✓ Alignment post assembly aids	
✓ Press interference fit	

Mag Link Assembly Updates Simplify Assembly, Eliminate Tuning, And Reduces Cost



# Antenna Assembly

## IMPROVEMENTS FOR MOD 1

### ▪ Performance:

Dielectric improvement

ESD protection improvement

### ▪ Cycle Time:

Simplified assembly

### ▪ Yield:

Automation increases yield

Cp better on target

Cpk increase

### ▪ Cost:

Component cost reduction

## MOD-1

- ✓ Simplified geometry
- ✓ Improved quality process & controls

- ✓ Standard coax cable connectors
- ✓ Consistent & repeatable performance

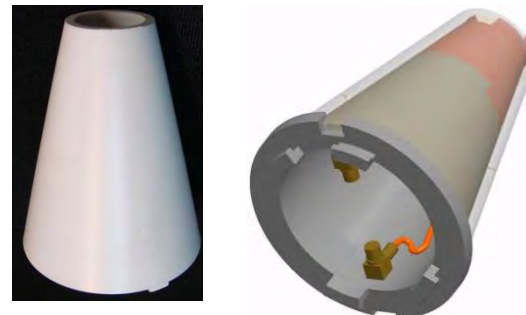
- ✓ Excellent, proven dielectric control

Improved design margin on:

- ✓ Return loss
- ✓ Isolation
- ✓ 2-way gain

- ✓ Autoclave bond film.

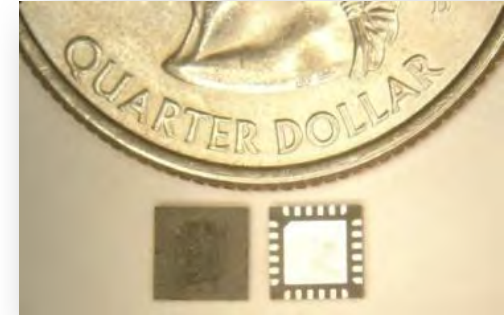
- ✓ Survived extensive ATK air gun shock tests
- ✓ Rail gun test successful.



Antenna Assembly Updates Eliminate Tuning, Simplify Assembly, And Reduces Cost

# MMIC Receiver

- ✓ MOD1 Receiver successfully designed, repackaged, built, and tested
- ✓ Increased LO drive range helps eliminate expensive unit tuning
- ✓ Successfully integrated and tested Receiver MMIC



## IMPROVEMENTS FOR MOD 1

### ▪ Performance:

ESD protection improvement  
Design margin improvement

### ▪ Cycle Time:

Eliminate unit to unit tuning

### ▪ Yield:

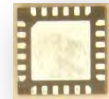
Cp better on target  
Cpk increase

### ▪ Cost:

Reduced chip size

### MOD-1

- ✓ Miniaturized 4x4mm QFN
- ✓ Integrated onto Controller PWB
- ✓ Standard pick-n-place and reflow
- ✓ Added ESD protection to improve reliability
- ✓ Significantly improved design margin
- ✓ Eliminates unit to unit tuning



Significantly Improved Design Margin Helps Eliminate Unit Tuning And Reduces Cost

# MMIC Transmitter

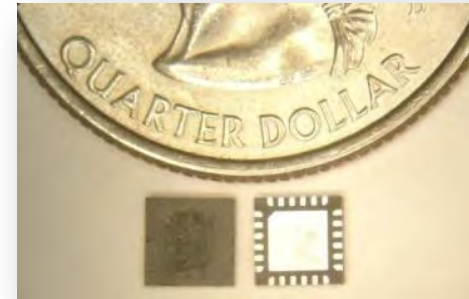
PIP planned two Transmitter MMIC design iterations

## 1<sup>st</sup> Design Iteration

- Vendor modeling error resulted in faulty ESD cells
- Vendor fused cells open, resulting in spec compliant MMICs
- Successful integration testing

## 2<sup>nd</sup> Design Iteration

- ✓ Updated design for ESD cell
- ✓ Updated core design to re-center frequency & increase output power (yield improvements)
- ✓ Modulation Port Sensitivity Pulling reduced range and opened specification. Reduced resistor binning.



## IMPROVEMENTS FOR MOD 1

### ▪ Performance:

ESD protection improvement

### ▪ Cycle Time:

Eliminate unit to unit tuning

### ▪ Yield:

Cp better on target

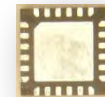
Cpk increase

### ▪ Cost:

Reduced chip size

### MOD-1

- ✓ Miniaturized 4x4mm QFN
- ✓ Integrated onto Controller PWB
- ✓ Standard pick-n-place and reflow



- ✓ Added ESD protection diodes to improve reliability
- ✓ Unit to unit variations minimized
- ✓ Eliminates unit to unit tuning

Reduced Unit-to-Unit Variation Helps Eliminate Unit Tuning And Reduces Cost

# Controller Circuit Card Assembly

## IMPROVEMENTS FOR MOD 1

### ▪ Performance:

Reduced power consumption

### ▪ Cycle Time:

Reduced soldering

Standard reflow

### ▪ Yield:

Automation increases yield

Cp better on target

Cpk increase

### ▪ Cost:

Reduced chip size

Integrate PWBs

## MOD-1

- ✓ Integrated into one PWB
- ✓ Panel fits twice as many PWBs



- ✓ Obsolete parts resolved
- ✓ Miniaturized components

- ✓ New potting eliminates component staking
- ✓ Improved component clearances for potting flow

- ✓ Improved component clearances
- ✓ No taping required

- ✓ Improved clearance and fitment

- ✓ Standard connectors used for PWBs and Antenna


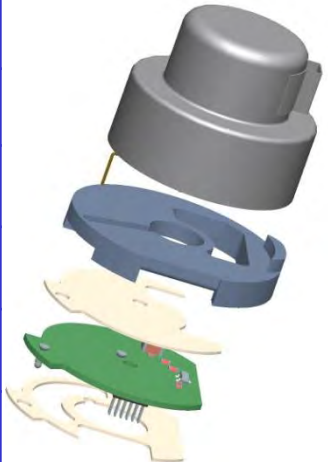
- ✓ Standard re-flow process
- ✓ Repackaged and decreased power consumption

Controller Assembly Updates Simplify Assembly, Eliminate Tuning, And Reduces Cost

# Fuze Housing And Battery Assembly

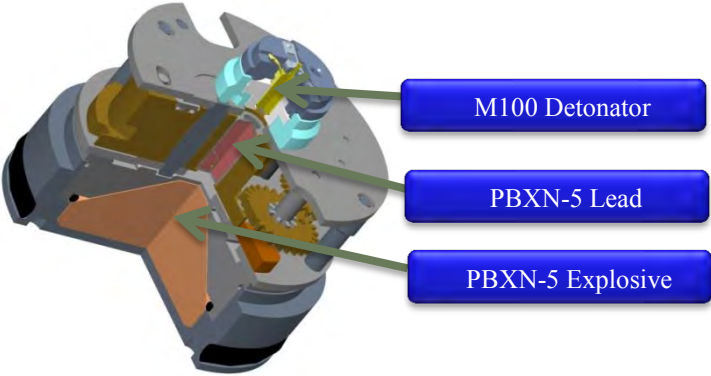
## IMPROVEMENTS FOR MOD 1

- **Performance:**  
Improved battery
- **Cycle Time:**  
Integrated fuze housing
- **Yield:**  
Reduced steps increases yield
- **Cost:**  
Reduced chip size  
Integrate PWBs

MOD-1	
<ul style="list-style-type: none"> <li>✓ Integrated into one part</li> <li>✓ Simplified assembly</li> </ul>	
✓ Lithium-SOCl2 reserve battery	
✓ Standard sockets	
✓ Simple assembly done outside of fuze	
✓ Eliminated shimming	
✓ Miniaturized components	
✓ Firing cap re-sized for M100	




Fuze & Battery Assembly Design Updates Simplify Assembly And Reduces Cost

# Detonator Assembly, S&A, And Booster



## IMPROVEMENTS FOR MOD 1

- **Performance:**  
Improved detonator
- **Cycle Time:**  
Easy Detonator Assembly
- **Yield:**  
Reduced steps increases yield
- **Cost:**  
N/A

MOD-1	
✓ M100	
✓ Detonator test points accessible	
✓ Simple assembly done outside of fuze	
✓ Redundant positive and ground contacts	
✓ Unchanged from MOD-0	
✓ Unchanged from MOD-0	

Detonator Assembly Simplifies Assembly And Reduces Cycle Time



# Battery

- MOD0 MK44 Lead Acid Reserve Energizer is obsolete
- Previous MFF studies identified and tested a replacement battery:

## Lithium-SOCL2 Reserve Battery

### IMPROVEMENTS FOR MOD 1

- **Performance:**  
Improved rise time
- **Cycle Time:**  
N/A
- **Yield:**  
N/A
- **Cost:**  
Battery cost reduced



MOD-0: MK44 Lead Acid  
Reserve Energizer



MOD-1 Lithium-SOCL2  
Reserve Battery

### PIP Design Results

- |   |  |
|---|--|
| ✓ | Batteries Procured                               |
| ✓ | Simplified Assembly                              |
| ✓ | Battery Tests Verify Battery Exceeds Goal        |
| ✓ | Battery Tests Verify Rise Time Exceeds Threshold |
| ✓ | Simulation & Lab Tests Verify Functionality      |

Battery Characteristics Exceed Fuze Requirements and Reduces Cost

# Summary

## ✓ PERFORMANCE:

- Going forward for HSMSTs
- New hardware has improved tolerance

## ✓ CYCLE TIME:

- 72 parts for Mod 0 compared to 40 parts for Mod 1
- Mod 1 Cycle Time is reduced by 65%

## ✓ YIELD:

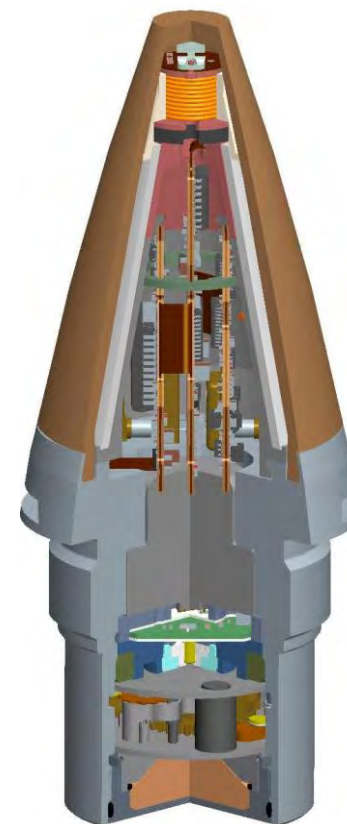
- Less steps for Mod 1 than Mod 0, less manipulation error
- Automation means better Cp and increased Cpk (better yield)

## ✓ COST:

- Electrical component cost less due to Moore's Law
- Moore's Law: in 10 years same component price drops by 100x

## Acknowledgements:

Mr. James Ring – ATK Technical Lead  
Mr. Marty Davis – ATK Program Manager



MOD-1 Design Updates Successfully Meets Performance, Cycle Time, Yield, and Cost

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# 55th Annual Fuze Conference

## Fuzing„s Evolving Role in Smart Weapons

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### **Development of a new MEMS High-g Accelerometer**

**R. Külls,**  
S. Nau, S. Heß, N. Pilous  
Fraunhofer Ernst-Mach-Institut EMI

Salt Lake City, May 26th 2011

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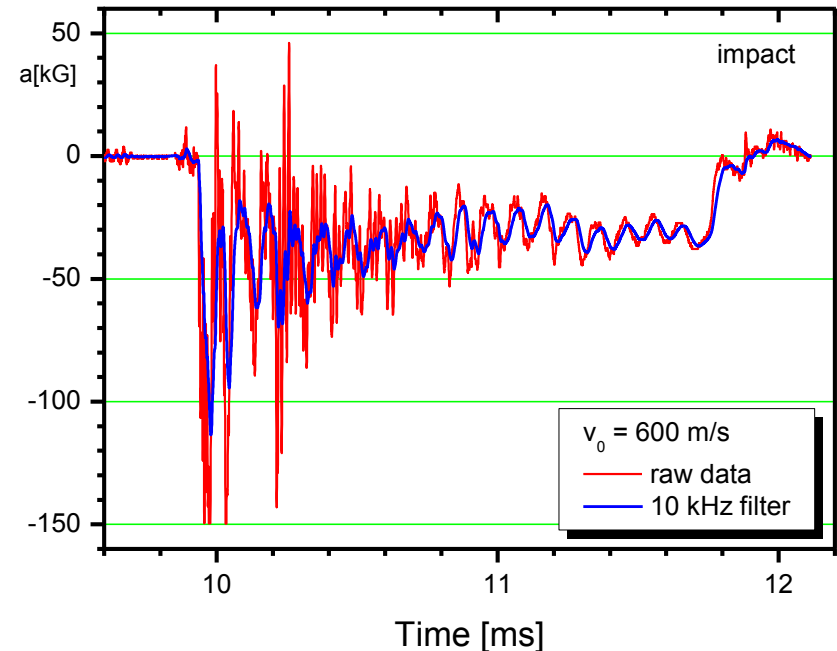
# OUTLINE

---

- Introduction
  - High-g Applications
- Theory
  - Transient Excitations
- Design
- First Experimental Data
  - Hopkinson Bar
  - 200,000 g Measurement
- Summary and Outlook

# High-g Applications: Research

- Analysis of highly dynamic processes
  - Shock-testing of electronics  
Measurement range needed:  
50,000 g
  - Material characterization  
g-Range > 80,000 g
  - Penetration processes  
g-Range > 100,000 g
  - Near field blast  
g-Range > 100,000 g



# High-g Applications: Military

Pictures: Wikipedia

- High-g hardened fuzing in smart weapons
  - Large warheads
  - Artillery shells
  - Upcoming:  
Smaller calibers  
> 100,000 g
- The smaller the ammunition, the bigger the acceleration



© EMI



# High-g Applications: Military

Pictures: Wikipedia

- High-g hardened fuzing in smart weapons

- Large warheads
- Artillery shells
- Upcoming:  
Smaller calibers  
> 100,000 g

Requirements:  
g-Range  
Survivability  
Size

- The smaller the ammunition, the bigger the acceleration

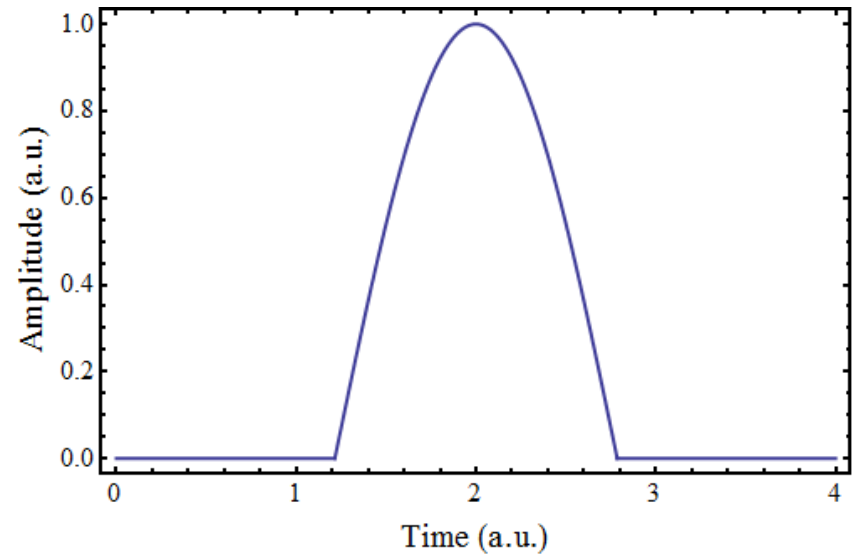
- Need for small, affordable  
(very-)high-g accelerometer



# Basics of High-g Accelerometry

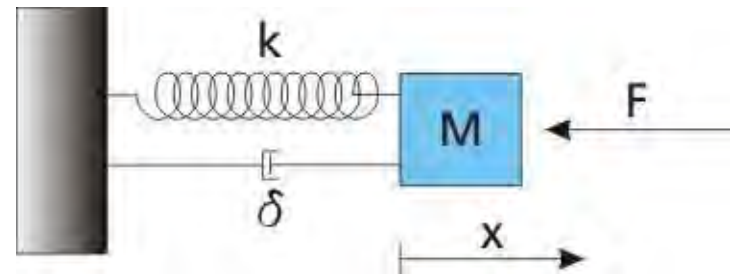
## ■ Shock pulse:

- “short“, “discontinuous“, “rapidly varying“



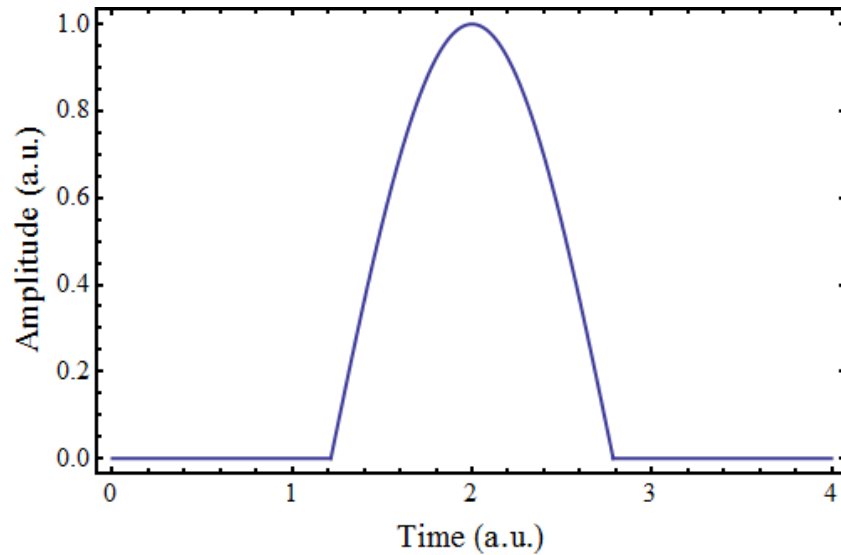
## ■ Accelerometer:

- Spring-mass-system with resonant frequency
- Displacement results in signal

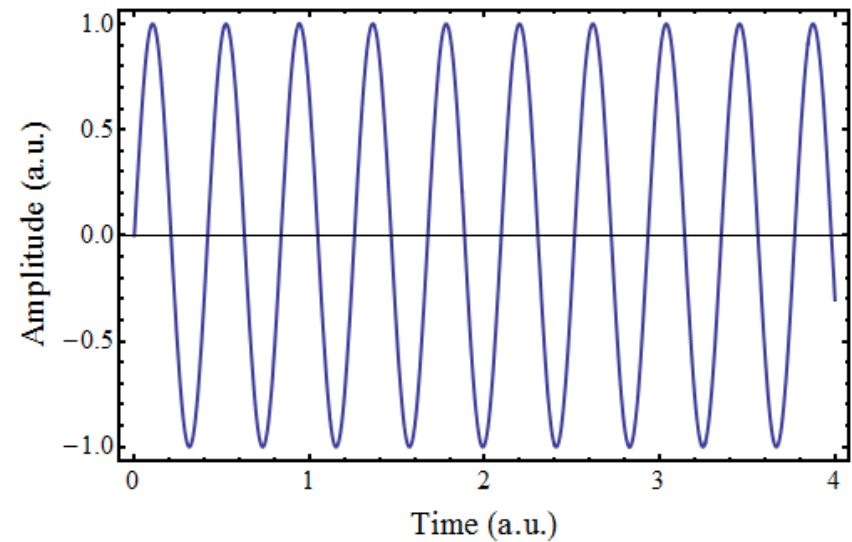


# Excitation of a Spring-Mass-System: Sample Pulse

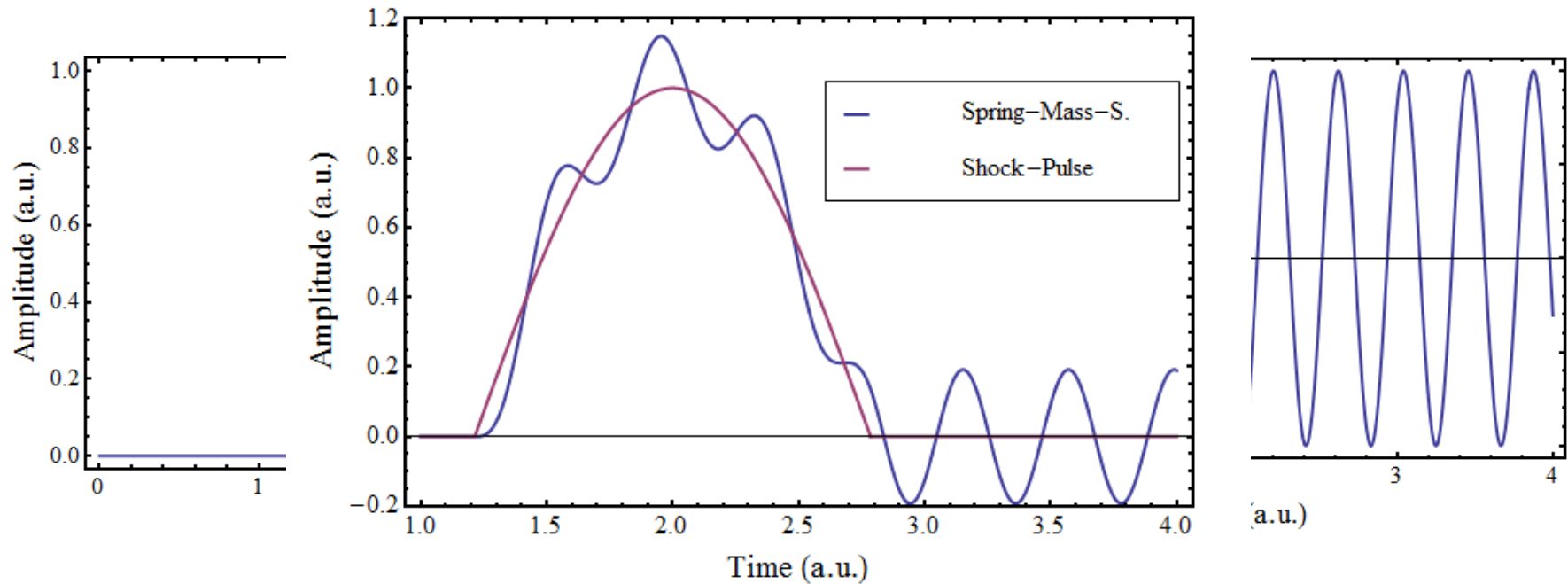
Shock-Pulse



Spring-Mass-System



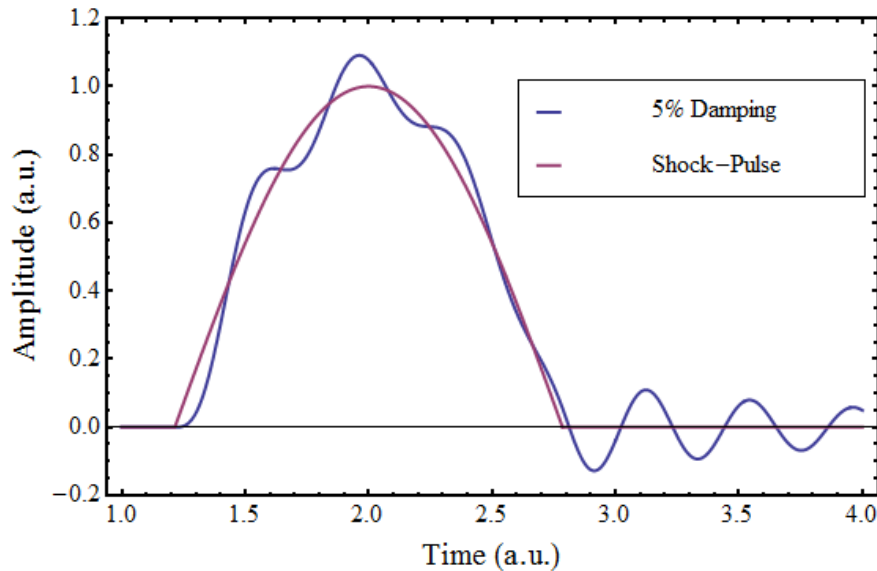
# Excitation of a Spring-Mass-System: Analytical Solution



## ■ How to avoid oscillations and over-excitation?

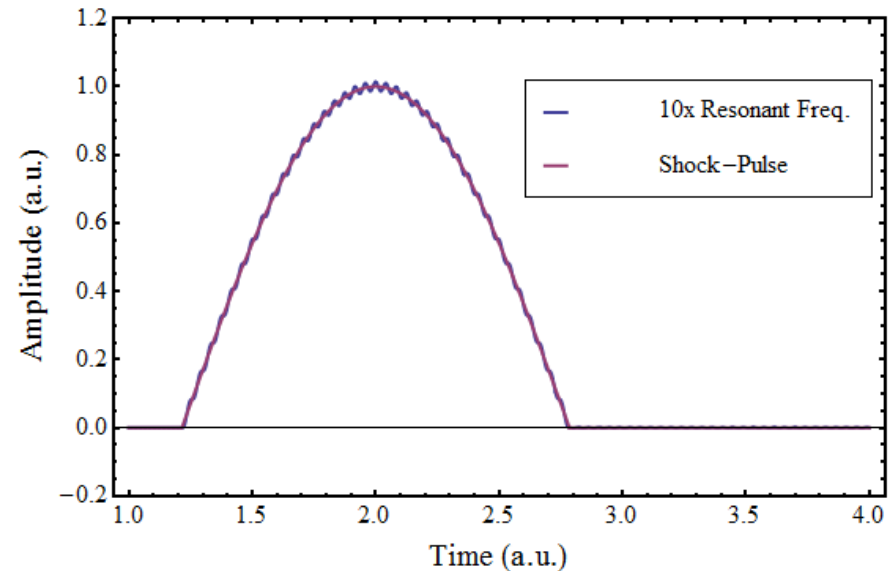
1. Damping (+ stops)
2. Higher resonant frequency

# Reducing Oscillations



## ■ 5% Damping:

- Over-excitation 15% -> 10%
- Oscillations 20% -> 10% -> 0%

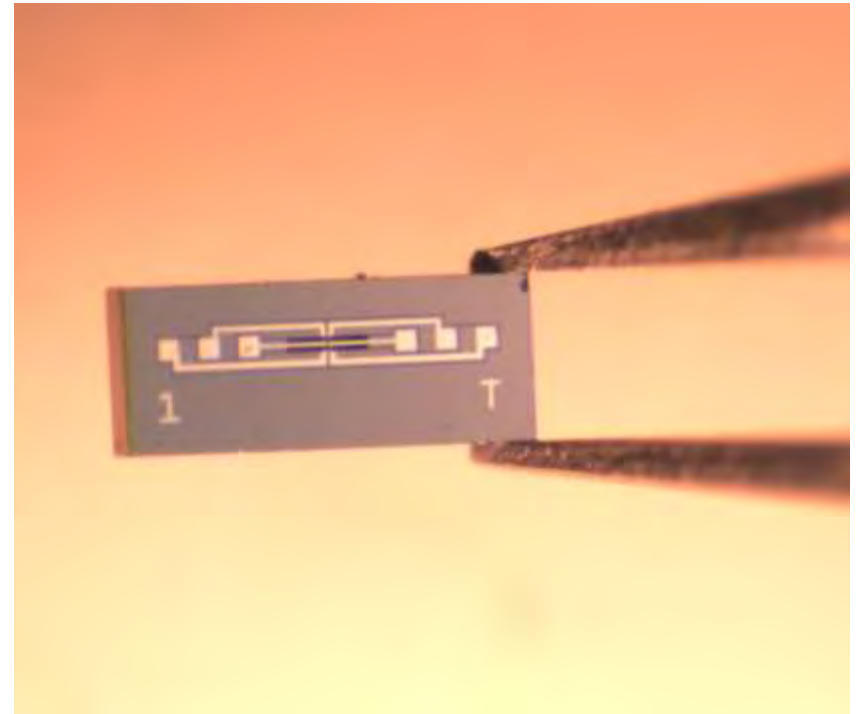


## ■ 10x Resonant Frequency:

- Over-excitation 15% -> 2%
- Oscillations 20% -> 2%

# EMI Accelerometer

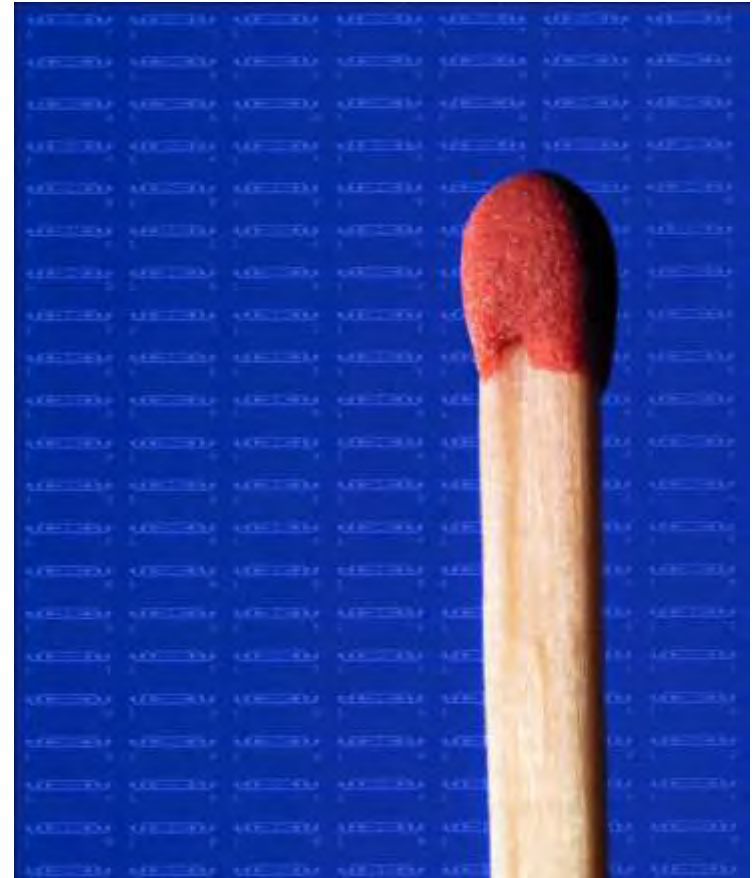
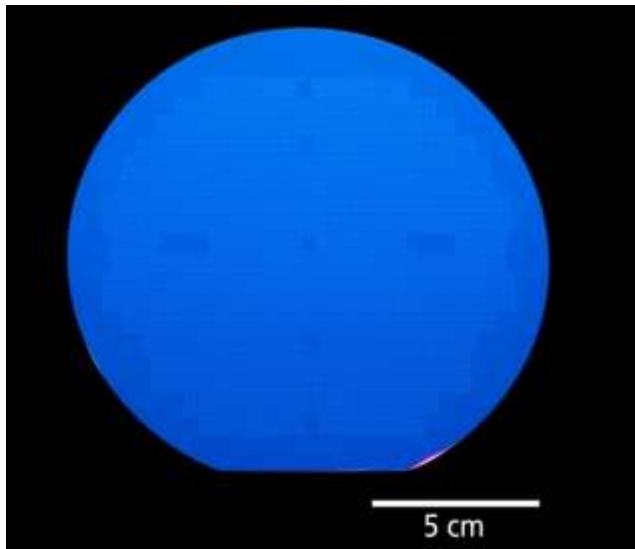
- Undamped, piezoresistive, MEMS accelerometer
- Status of development
  - Design is patent pending
  - First specimens were successfully manufactured and tested
- Different variants exist:
  - Measurement range  $> 100,000 \text{ g}$
  - Resonant frequency  $1 - 3 \text{ MHz}$
  - Sensitivity  $0.1 - 1 \text{ } \mu\text{V}/V_{\text{exc}}/\text{g}$





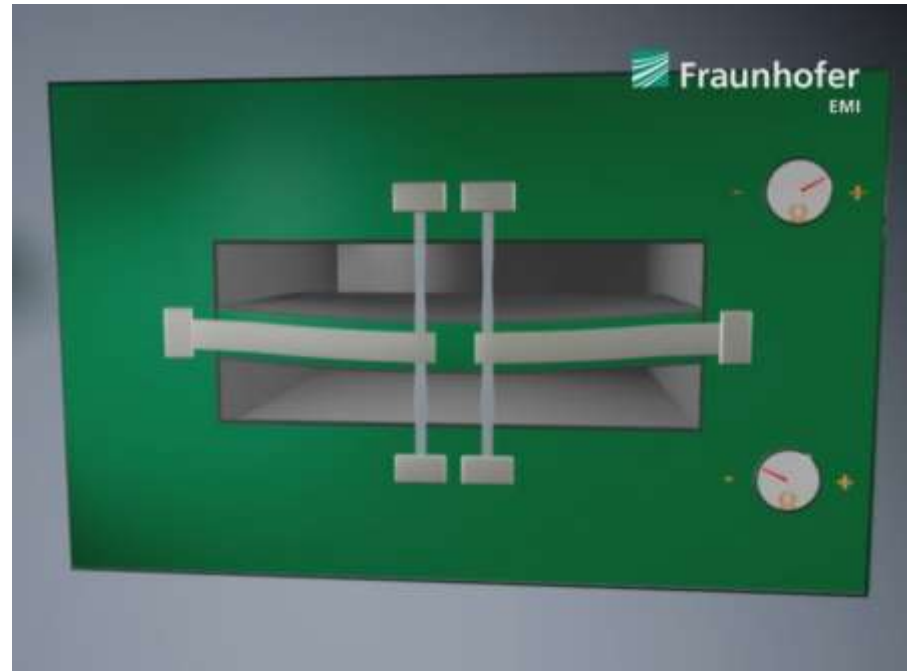
# EMI Accelerometer

- Manufactured with standard silicon processes, single sided
- Sensor-chip about  $2 \times 1 \text{ mm}^2$
- Straightforward integration of 2D and 3D measurement capabilities



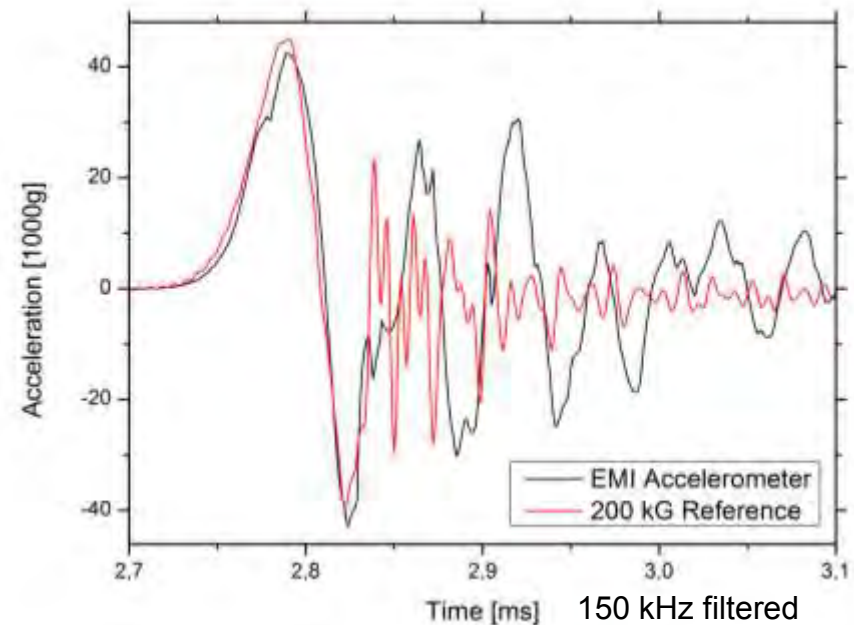
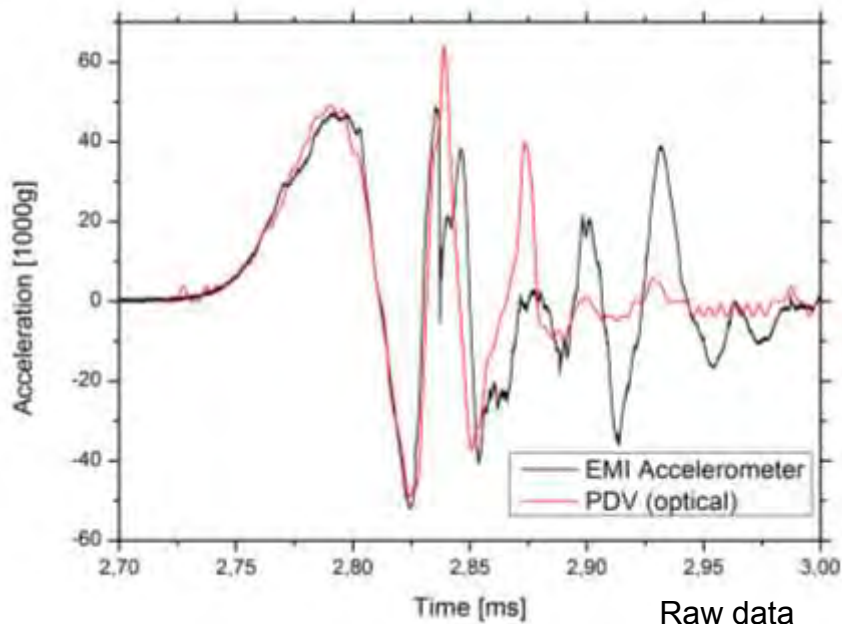
# EMI Accelerometer: Functional Principle

- Main components:
  - Flexural plate
  - Self-supporting piezoresistive elements
  - Full Wheatstone-bridge
- Functional principle:
  - Inertial forces cause deflection of plate
  - Straining of piezoresistive elements
  - Change in resistance is measurement signal

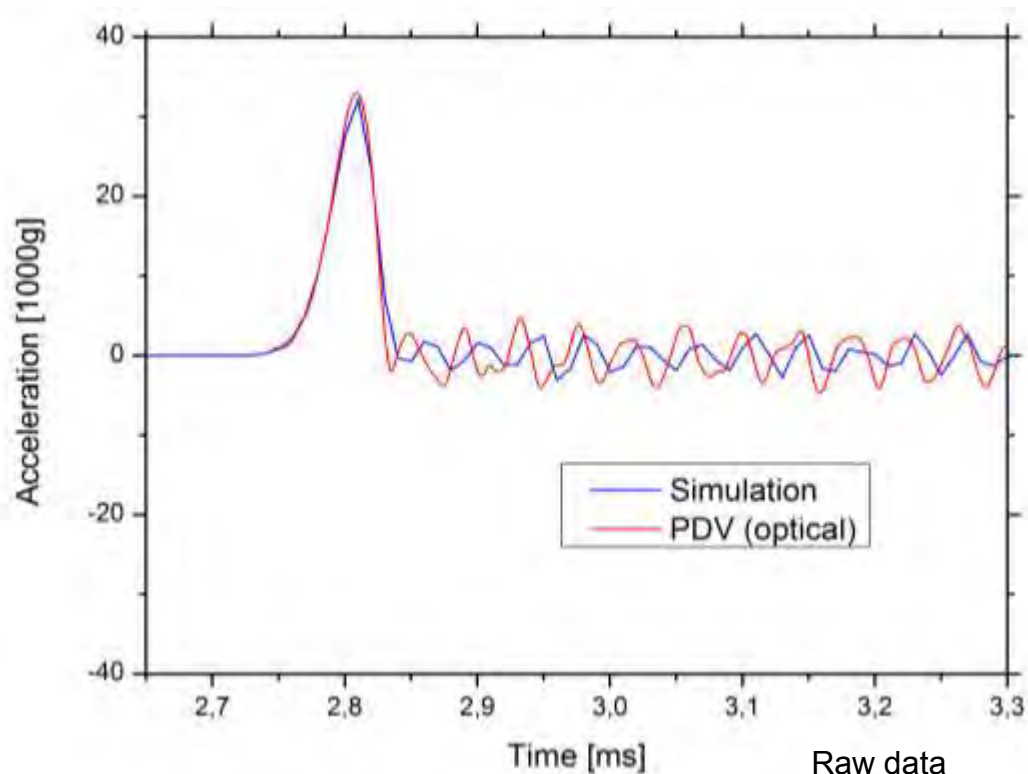


# Hopkinson Bar Measurements

- Assessment of accelerometer performance on Hopkinson bar
- Comparison:
  - First peak well reproduced
  - Differences after breakaway

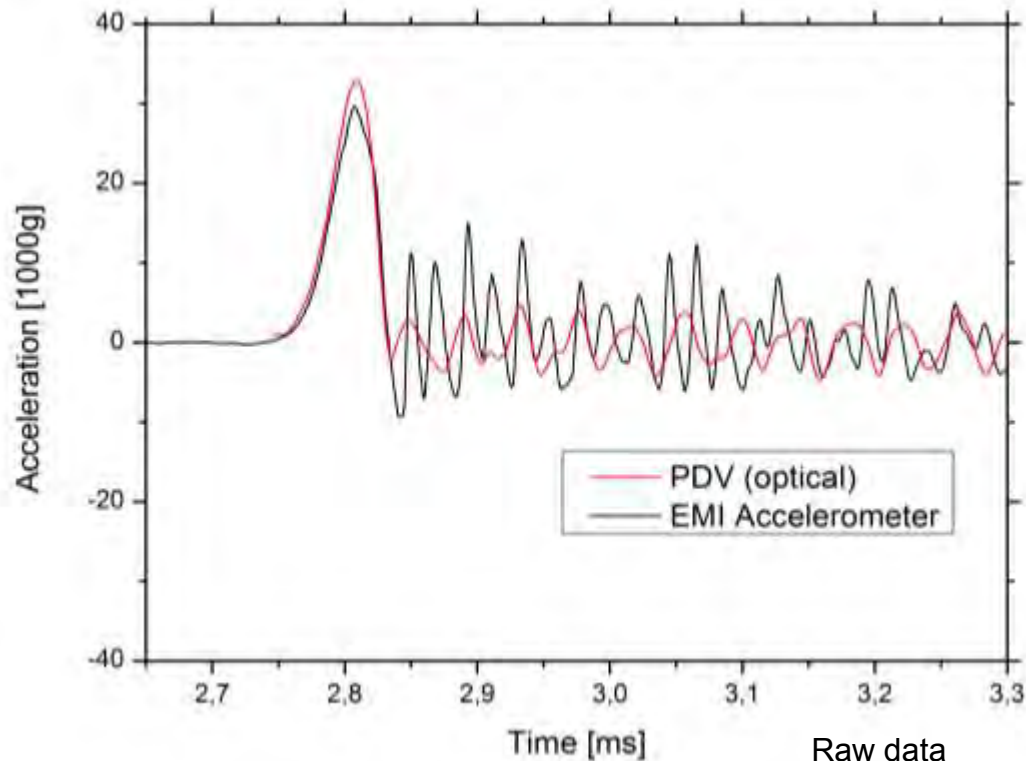


# Shock Plate Test: Reference



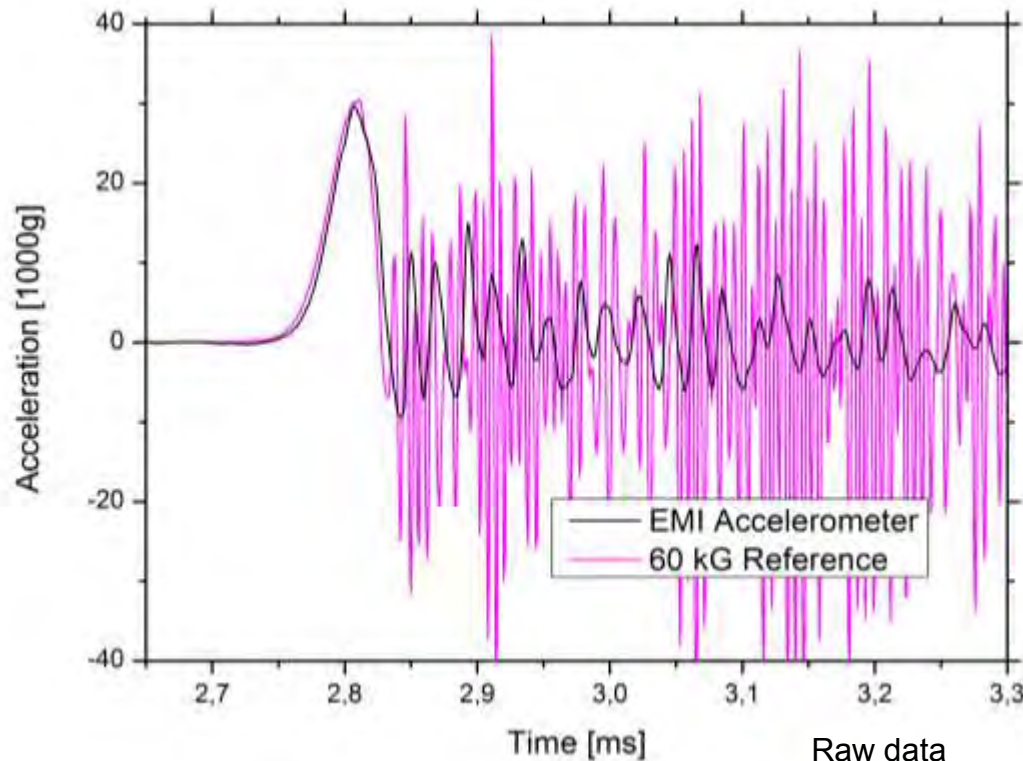
- Test of accelerometers on shock plate
- Simulation and reference measurement with PDV
  - 30,000 g pulse
  - Plate shows oscillations with 23 and 46 kHz (1<sup>st</sup> and 2<sup>nd</sup> harmonic)

# Shock Plate Test: Comparison



- Second flyer plate experiment with EMI accelerometer and 60 kG lightly damped sensor
- 2<sup>nd</sup> harmonic more distinct in this test

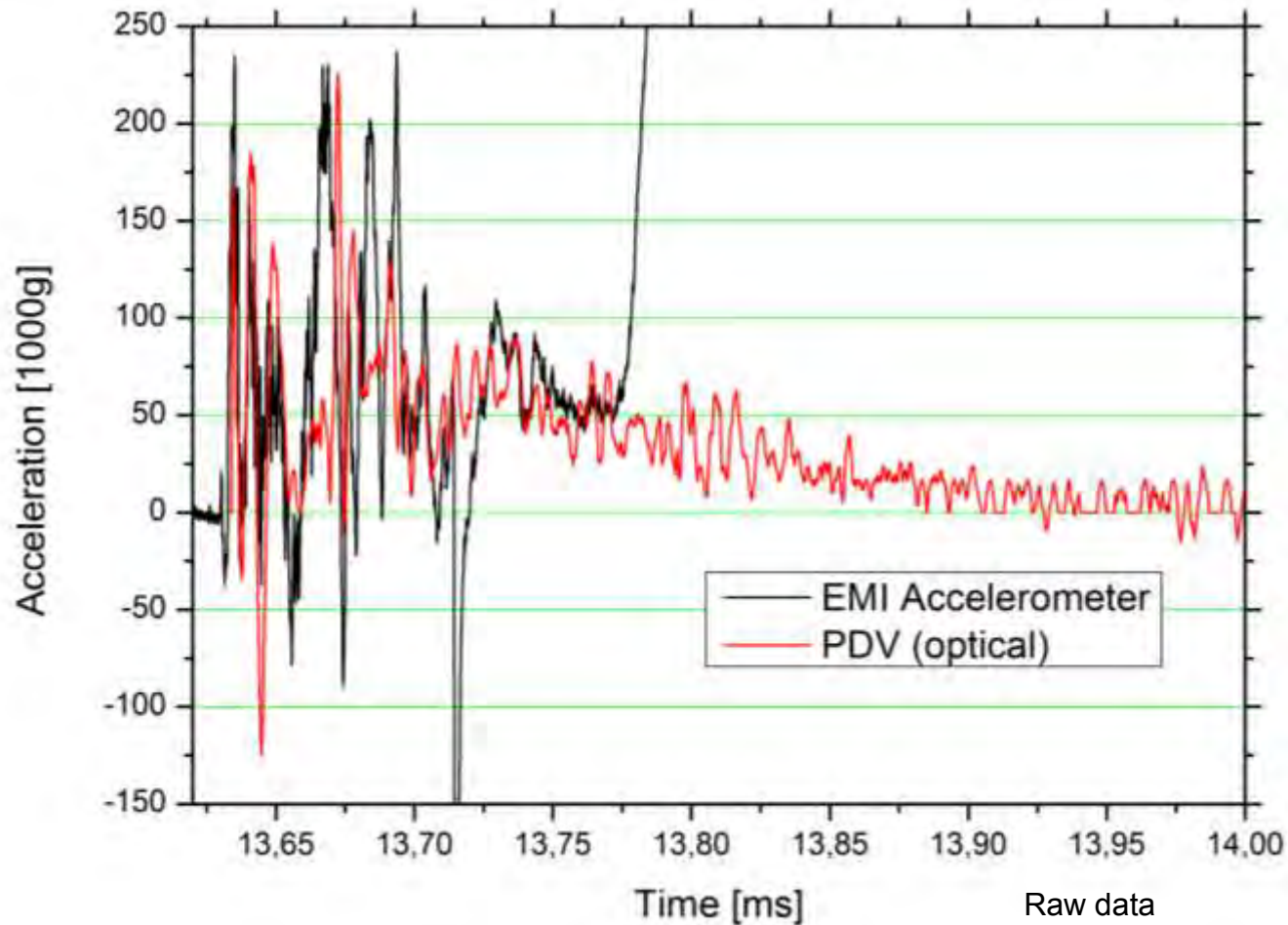
# Flyer Plate Test: Comparison



- Second flyer plate experiment with EMI accelerometer and 60 kG lightly damped MEMS
- 2<sup>nd</sup> harmonic more distinct in this test
- Both sensors reproduce first peak
- EMI: Plate oscillations with 23 and 46 kHz are well visible
- 60 kG: 165 kHz resonant frequency overlays plate dynamics

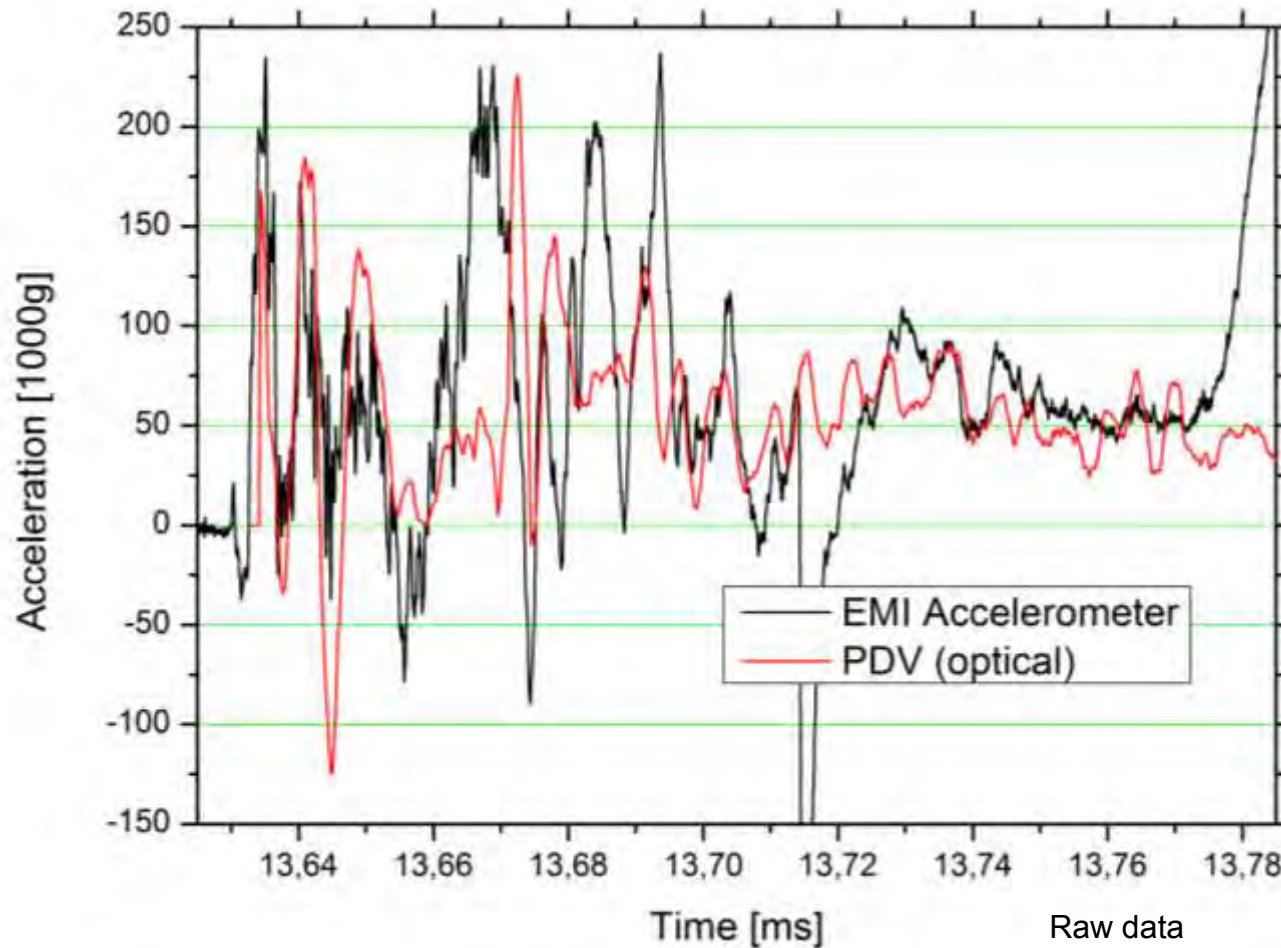


# 200,000 g Measurement



- Impact experiment with PDV measurement
- Overall agreement is good
- Failure of cable connection

# 200,000 g Measurement



- Confirmed acceleration over 200,000 g
- Defective contact at 13.72 ms and failure of cable at 13.78 ms
- No resonant oscillation
- Sensor-chip is completely intact!

# Summary

- EMI accelerometer has been designed and manufactured
  - Design patent pending
  - Standard silicon processes
  - Successful proof of concept
  
- The EMI design combines:
  - ... the sensitivity of medium g-range sensors (  $> 0.2 \mu\text{V}/V_{\text{exc}}/\text{g}$ ) (proven)
  - ... with the survivability of high g-range sensors (  $> 200.000 \text{ g}$ ) (proven)
  - ... while having a uniquely high bandwidth (  $> 2 \text{ MHz}$ ) (not meas. yet)

# Outlook

- Determination of accelerometer performance is to be completed
- Further development will focus on:
  1. Realization of an “easy to use” and robust package
  2. Monolithical integration of bi- or tri-axial accelerometers

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# Thank you for your Attention!

This work was funded by the  
Federal Office for Defence Technology and Procurement BWB  
(Bundesamt für Wehrtechnik und Beschaffung)

## Further Information:

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# 55th Annual Fuze Conference

## Fuzing„s Evolving Role in Smart Weapons

---

### **Generation and Measurement of Long Duration High-g Acceleration Profiles**

**S. Nau,**  
V. Aust, N. Pilous  
Fraunhofer Ernst-Mach-Institut

Salt Lake City, May 26th 2011

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# OUTLINE

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- Introduction

- Need for Test Methods

- Generation of Long Duration Transients

- EMI Defined-Long-Duration Shock Test

- Application

- Choice and Test of Electronic Components

- Measurement of Long Duration High g-Acceleration Profiles

- Penetration of Concrete

“g-rec”

- Summary

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# Motivation

## Smart Weapons with Penetration Capability

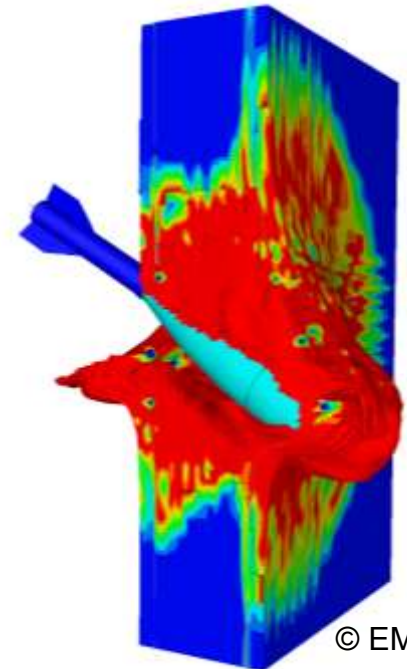
image: wikipedia

- High-g hardened fuzing
  - Large warheads
  - Upcoming: Smaller calibers as for precision guided munitions with moderate effect
$$a_{\max} > 100,000 \text{ g}$$

⇒ the smaller the ammunition,  
the bigger the acceleration

- No manufacturers specifications available for electronic parts for high-g-regime
- Inexplicable system failures in the field

⇒ need for reliable, cheap high-g-test methodology



# Required Test Methodologies for Sub-Scale Survivability Test

Fuze-Conference 2010:

D. Hayles, DTRA : Notional Shock Spectrum

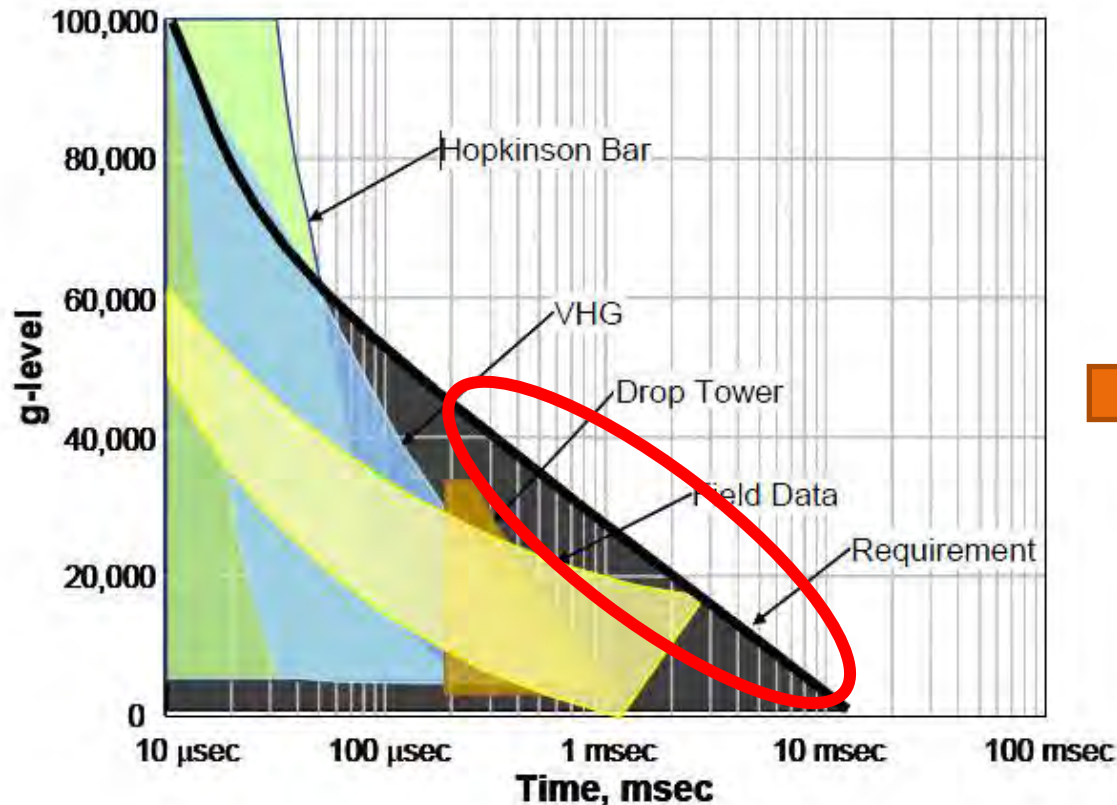


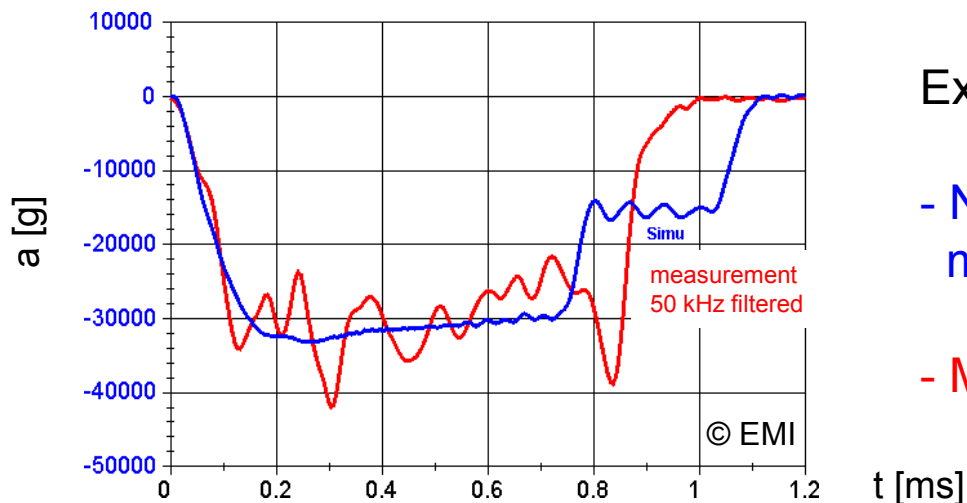
Photo Courtesy of AFRL/RWMF



technical requirement:  
 $V_{0, DUT} > 100 \text{ m/s}$

# EMI Defined-Long-Duration (DLD) Shock Test

- High initial velocity of actuator
  - ⇒ long duration *and* high amplitude load profiles
- Numerically tailored compression body
  - ⇒ quantitative load profile estimation
  - ⇒ new load regimes reproducible accessible
- Experimental validation by g-rec or PDV\* measurements



Example: 30.000 g, 800  $\mu$ s

- Numerical prediction: movement of center of gravity
- Measurement inside sample holder

\* PDV: Photonic Doppler Velocimetry

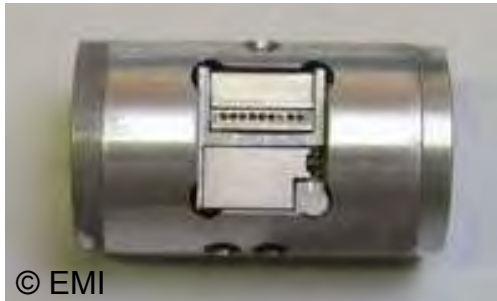
# EMI Defined-Long-Duration (DLD) Shock Test

## ■ Current R&D-setup:

- $m_{(\text{Device Under Test})}$  up to 200 g
- $\varnothing < 34 \text{ mm}$ ,
- $l = 100 \text{ mm}$

} scalable to higher values

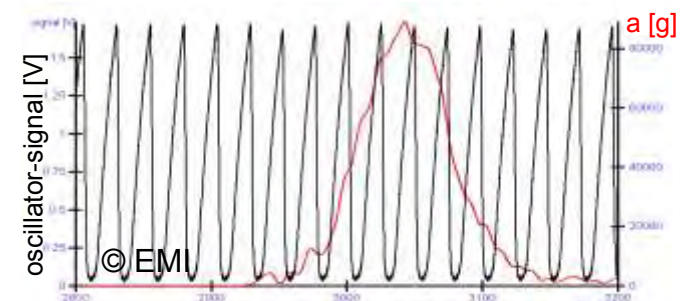
- If needed: Device under Test electrically connected
- Low temperature experiments ( $-46 \text{ }^{\circ}\text{C}$ ) possible
- Modest cost
- Extension to spinning systems is under way



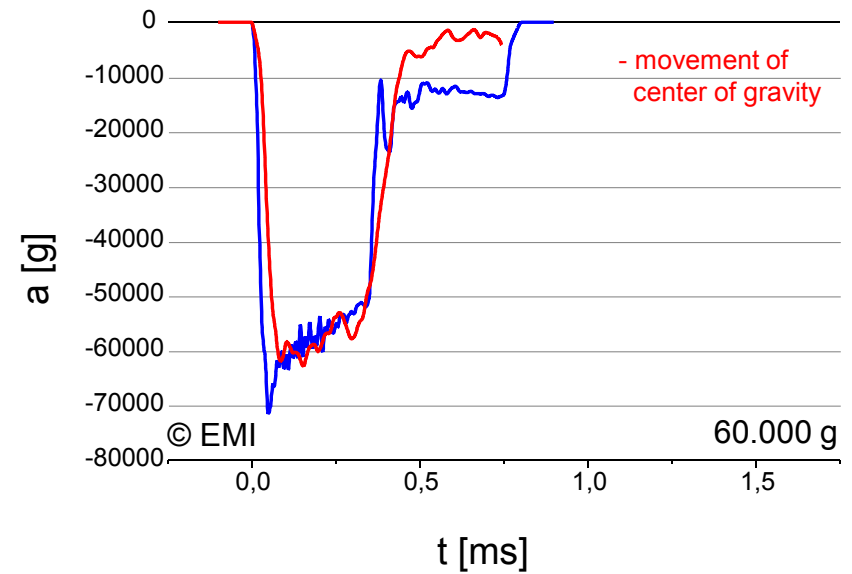
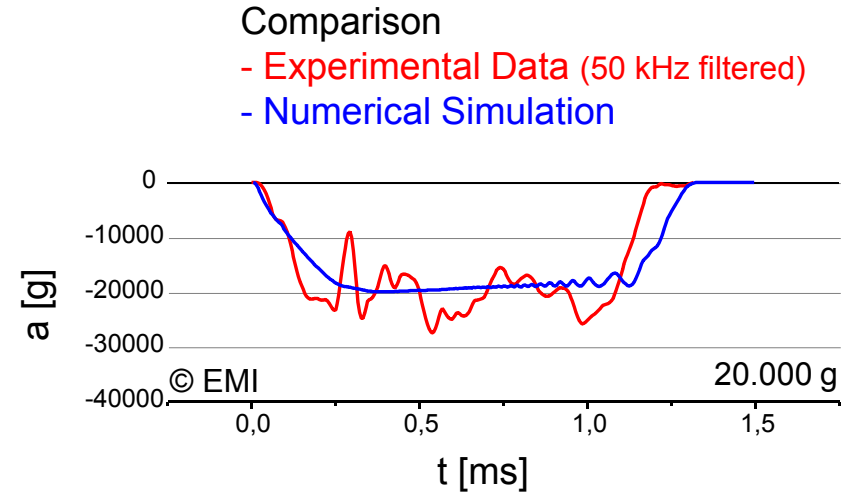
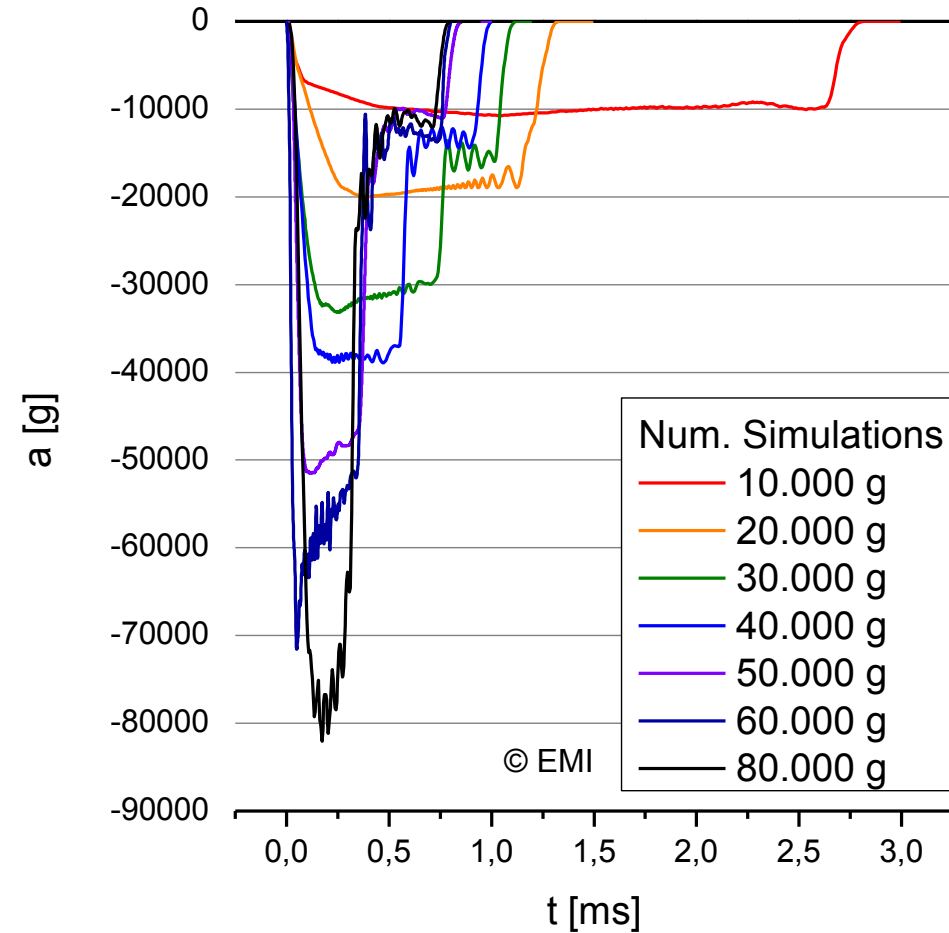
Exemplary sample holder



Example: 80.000 g oscillator-Test



# EMI - DLD - Shock Test





# EMI - DLD - Shock Test

# Experimental Results

D. Hayles, DTRA, Fuze Conference 2010

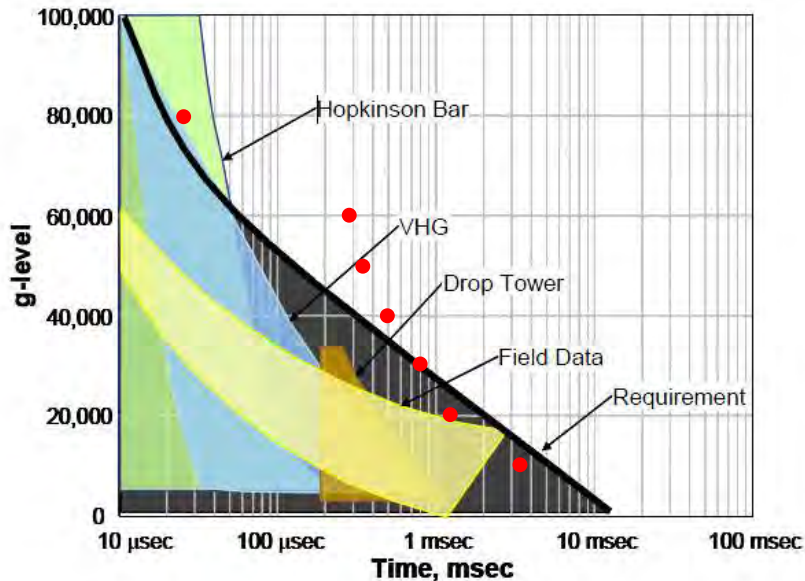


Photo Courtesy of AFRL/RWMF

Experiments were conducted in cooperation with industry partners and used for product development.

## EMI-DLD-Experiments

10.000 g	3.300 ms	(exp)
20.000 g	1.250 ms	(exp)
30.000 g	0.800 ms	(exp)
40.000 g	0.520 ms	(exp)
50.000 g	0.350 ms	(sim)
60.000 g	0.310 ms	(exp)
80.000 g	0.025 ms	(exp)
	0.300 ms	(sim)

Experiments validated by

- exp acceleration measurement or Photonic Doppler Velocimetry
- sim numerical Simulation *and* high-speed Video

# Application

## Choice and Test of Electronic Devices

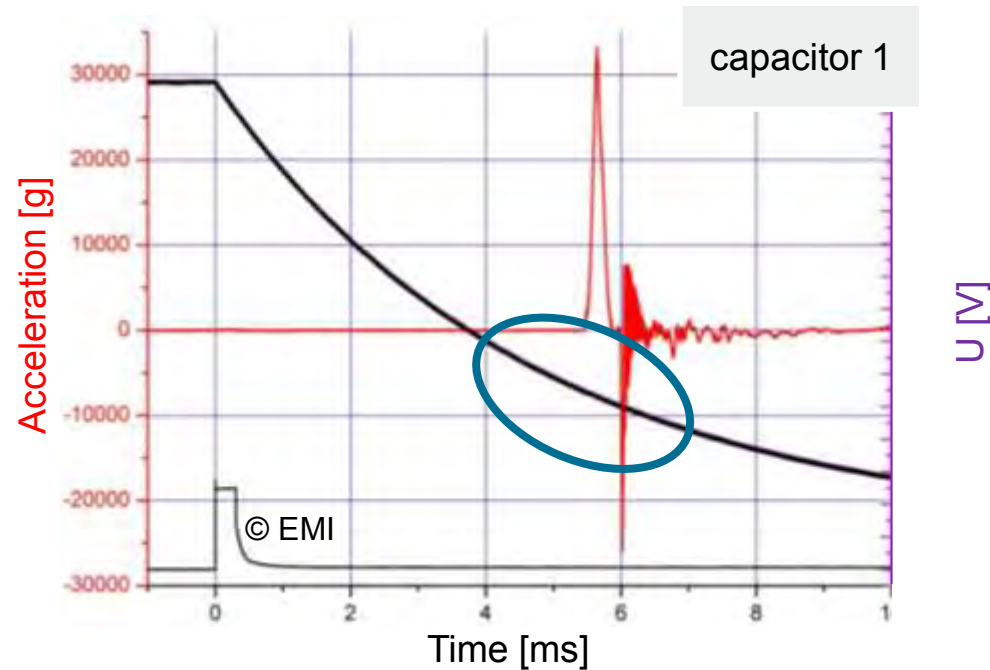
Device behavior upon high-g-loads:

- Intended function
- Disintegration of the device
- Malfunction only during load

⇒ DLD-Shock-Test with electrical access to relevant device properties during load

Example: Capacitor 1

⇒ intended function



# Application

## Choice and Test of Electronic Devices

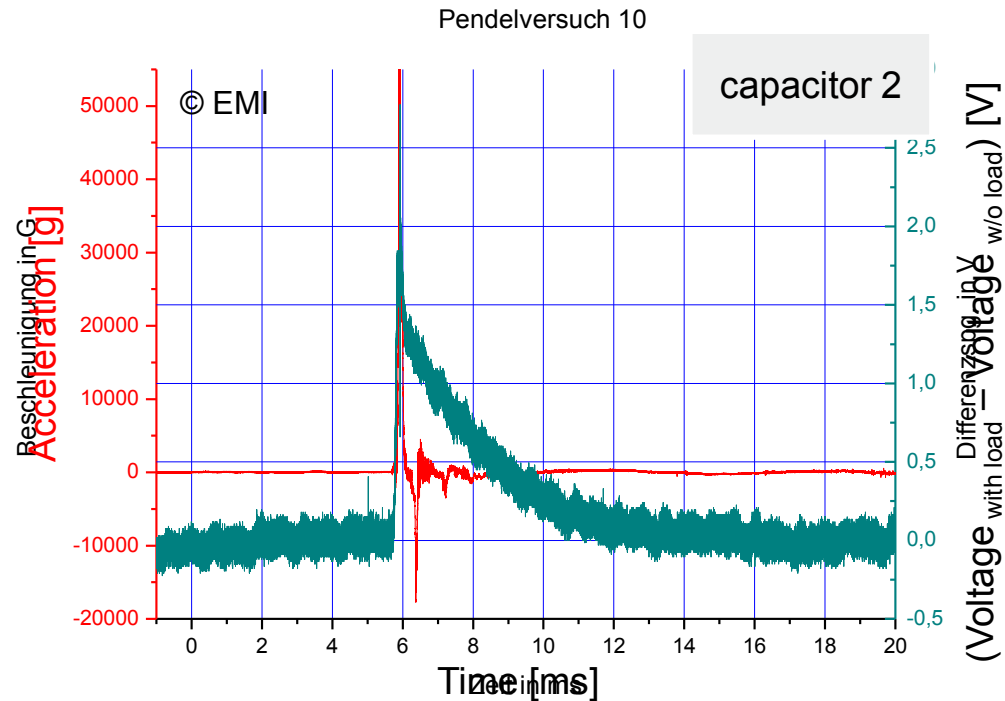
Device behavior upon high-g-loads:

- Intended function
- Disintegration of the device
- Malfunction only during load

⇒ DLD-Shock-Test with electrical access to relevant device properties during load

Example: Capacitor 2

- (Reversible) effect only during load !
- Pre- and post-mortem results could be misleading



Approach / solution :

- Usage of different devices, or device technologies
- Improved engineering concepts

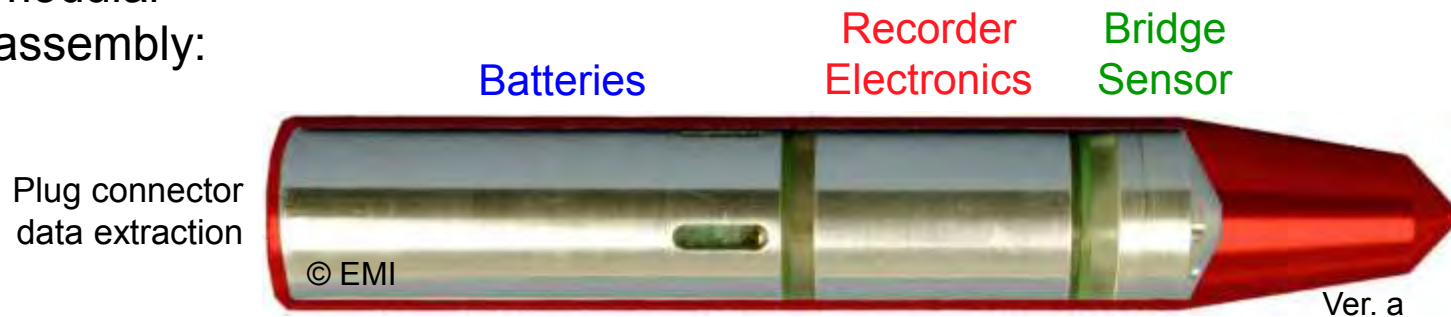
# Application g-rec

## Measurement of Long Duration High-g Acceleration Profiles

### Concept

- Autonomous digital data recorder with shock accelerometer
- Resistant to high accelerations and decelerations ( > 100,000 g, Ver. a)
- PC based data retrieval after projectile recovery

### modular assembly:



2 versions: a) hard-wired version

$\varnothing = 26 \text{ mm}$ ,  $l = 155 \text{ mm}$

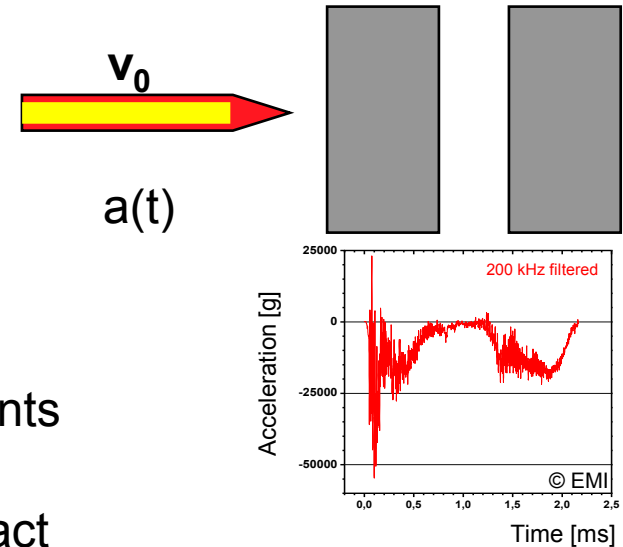
b) programmable, based on microcontroller

$\varnothing = 23 \text{ mm}$ ,  $l = 80 \text{ mm}$

# Application

## Measurement of Long Duration High-g Acceleration Profiles

- Investigation of penetration processes
  - Movement of the center of gravity
  - Characterization of mechanical properties of HE during impact conditions
- Stand alone data recorder for harsh environments
- Measurement tool for fuze systems during impact
- Investigation of interior dynamic of penetrators
  - Study of mechanical wave propagation and resonances
  - Damage mechanisms, ...



# Application

## Concrete Penetration

### Measurement of Long Duration High-g Acceleration Profiles

36 mm - penetrator equipped with g-rec:

Gun launch (powder cannon)

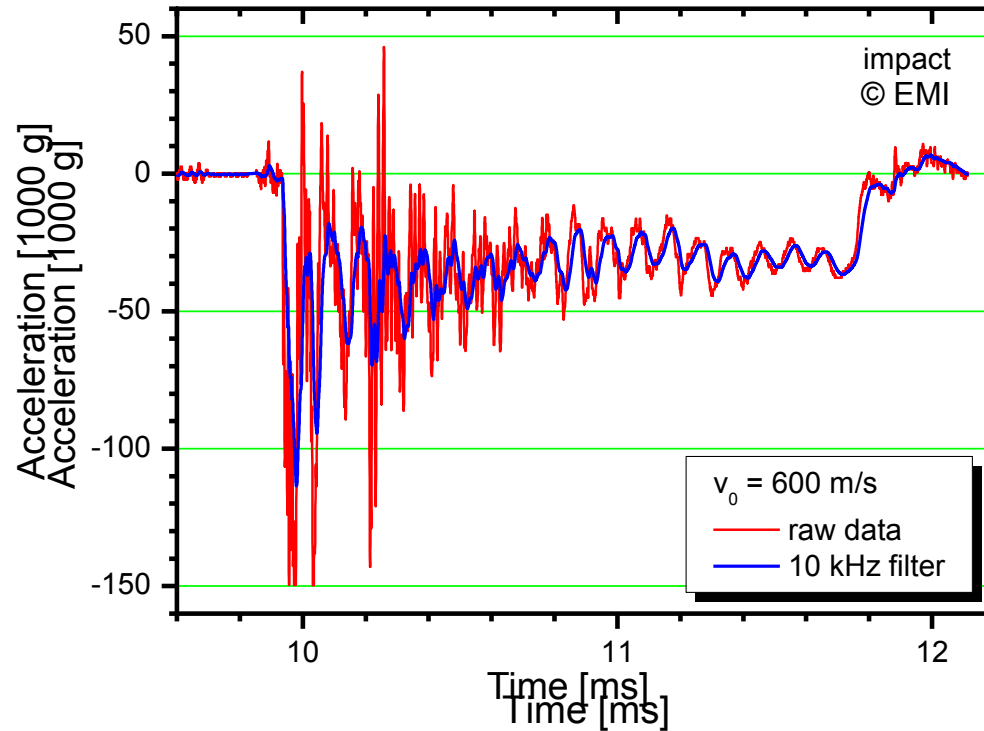
$$v_0 = 600 \text{ m/s}$$





# Application

## Concrete Penetration Measurement of Long Duration High-g Acceleration Profiles



# Application

## Concrete Penetration

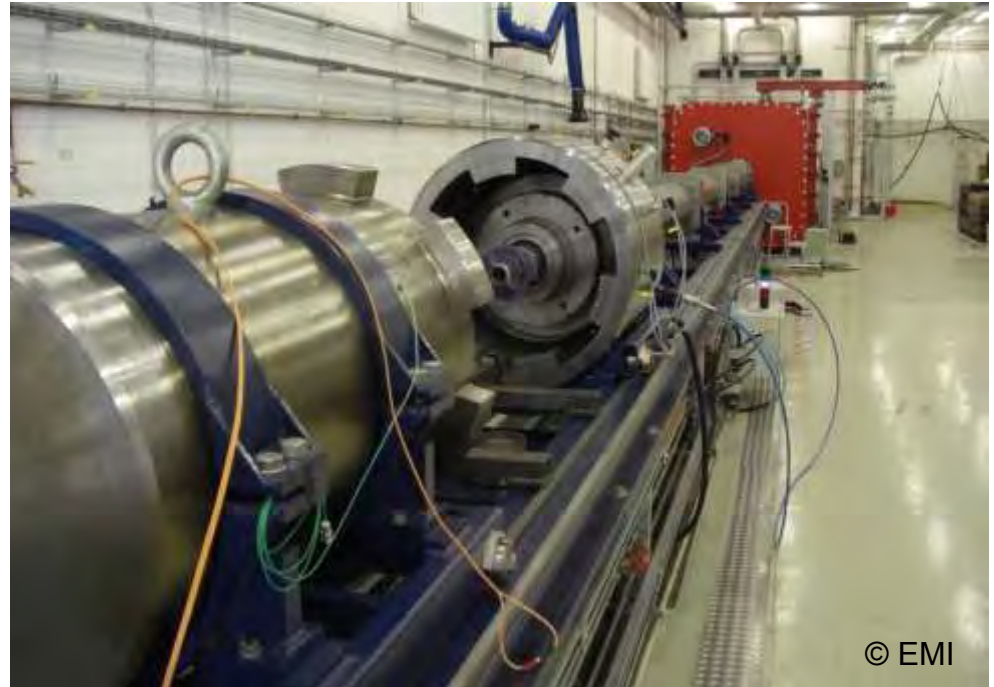
### Measurement of Long Duration High-g Acceleration Profiles

Experiments with 60 mm projectiles



© EMI

Projectile and sabot,  
projectile: cal. 60 mm



© EMI

150 mm-Facility,  
Ernst-Mach-Institute, Germany

# Application

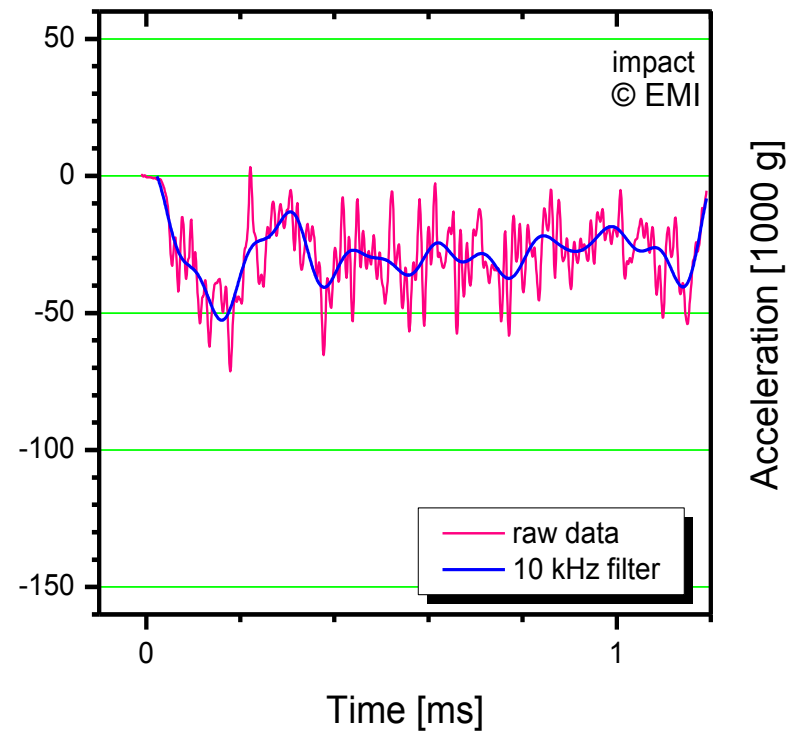
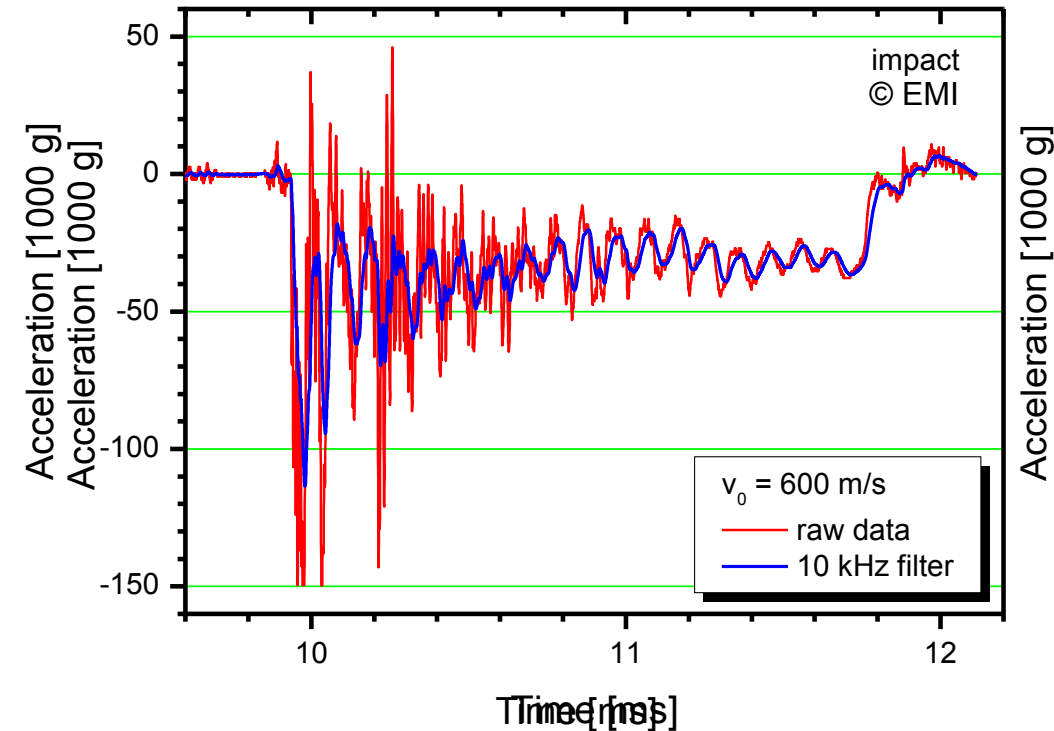
## Concrete Penetration

### Measurement of Long Duration High-g Acceleration Profiles

Interpretation after experiment, no real time processing.

caliber: 36 mm

caliber: 60 mm



⇒  $a_{\max, 36 \text{ mm}}$  more than two times higher than  $a_{\max, 60 \text{ mm}}$

# Summary

- EMI-DLD-Shock Test
  - Powerful test-method that covers interesting high-g-load and long duration pulse regime
  - Reproducible lab-test at moderate costs
- Application of DLD-Shock Test: behavior of capacitors during high-g-load
- Measurement of long duration shock pulses with autonomous data recorder
  - g-rec: versatile and robust measurement-tool
  - Medium caliber concrete penetration at high velocities
    - ⇒ the smaller the ammunition, the bigger the acceleration

---

# Thank you for your Attention!

## Questions?

This work was funded by the  
Federal Office for Defence Technology and Procurement BWB  
(Bundesamt für Wehrtechnik und Beschaffung)

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# Smart Materials for Fuzing

55<sup>th</sup> ANNUAL FUZE CONFERENCE

MAY 24, 2011

Presented By:

Daniel Pears

Scientist IV, L-3 Fuzing & Ordnance Systems

Perry Salyers, Ed Cooper

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This presentation consists of L-3 Corporation general capabilities information that does not contain controlled technical data as defined within the International Traffic in Arms (ITAR) Part 120.10 or Export Administration Regulations (EAR) Part 734.7-11.



# Outline

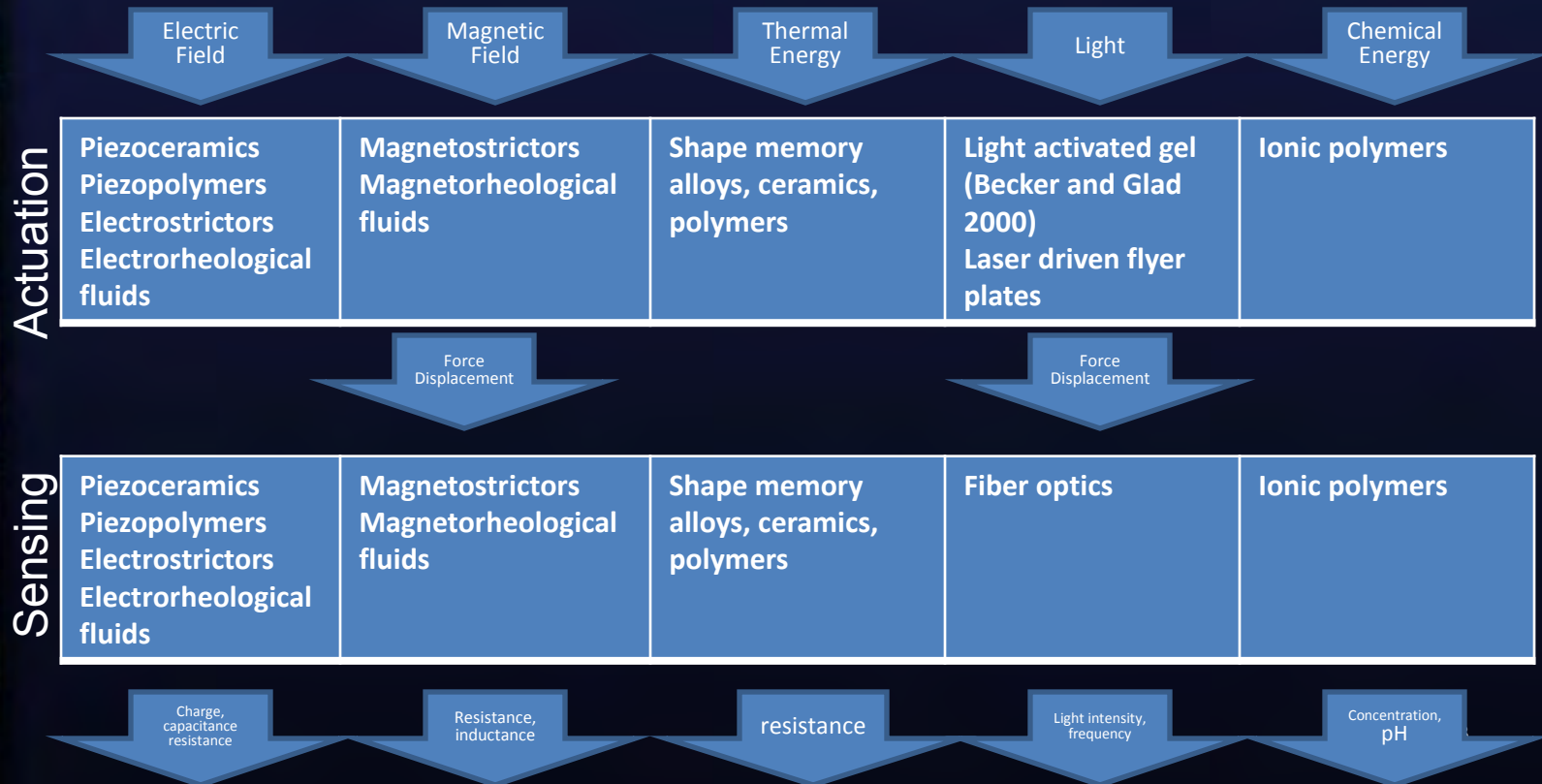
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- Presentation Objective: Review several smart materials and potential applications to fuzing and ordnance
- Smart material overview
- Piezoelectrics
  - *Damage sensing, power harvesting*
- Shape Memory/Superelastic Alloys
  - *IM, self-healing, safe & arm applications*
- Magneto/Electro-rheological Fluid
  - *Suspension, safe & arm*
- Conclusions



# Smart Material Classification

- Materials converting energy/fields into other (especially mechanical)
- Many definitions, other names and related areas
  - *Intelligent materials, multifunctional materials*



- Smart structures use these materials to provide integrated sensing, actuation or control and structural integrity

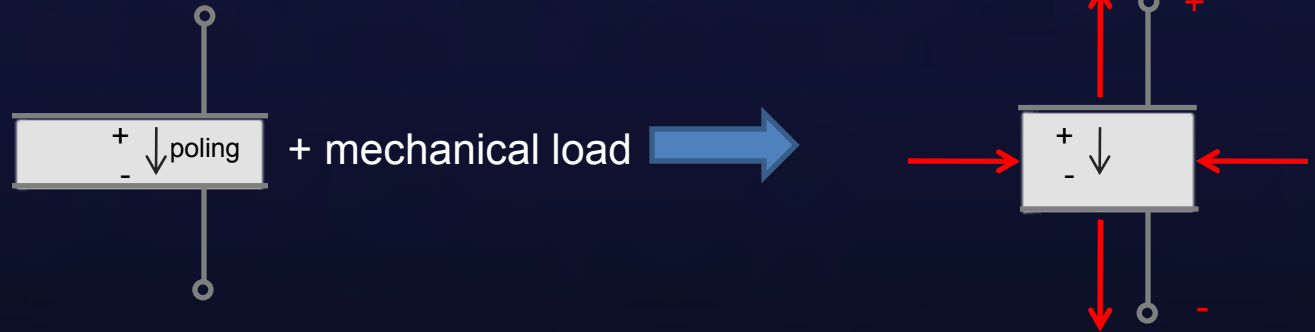
# Why Consider Smart Materials?

- Increased functionality
  - *Monitoring functions*
    - As munitions age, increased likelihood of malfunctions.
    - Sensing solutions can help predict individual or subpopulation reliability
  - *Environment sensing*
    - Both during storage and at use
  - *Adaptivity*
    - Shape morphing and control
    - Self repair
- Reduced size
  - *Higher energy density*
  - *Smaller munitions*
  - *Smarter munitions*
    - Fit more into the provided space
      - Integrated fuzing guidance and targeting



# Piezoelectric Background

- Generally high force/ low stroke
- Direct effect
  - *Generates electric charge with applied force*



- Converse effect
  - *Generates mechanical force/ displacement from electric field*





# Piezoelectric Material Background

- Piezoelectric effect found in crystals, ceramics polymers and biological materials
- Common piezoceramics lead zirconate titanate (PZT), Barium titanate, lead metaniobate (PMN)
- PZT – high piezoelectric and dielectric constants
  - Many formulations of PZT exist – Hard, soft
- DOD-STD-1376 - Originally defined standard material types for Hydrophones
  - *DOD or Navy Type I- VI*
  - *Hard or soft, Curie point, Self heating susceptibility (high electric drive potential)*
- Manufacturers generally report material properties



# Material Modeling

- 3D constitutive equations

$$\begin{bmatrix} S_1 \\ S_2 \\ S_3 \\ S_4 \\ S_5 \\ S_6 \end{bmatrix} = \begin{bmatrix} s_{11}^E & s_{12}^E & s_{13}^E & 0 & 0 & 0 \\ s_{21}^E & s_{22}^E & s_{23}^E & 0 & 0 & 0 \\ s_{31}^E & s_{32}^E & s_{33}^E & 0 & 0 & 0 \\ 0 & 0 & 0 & s_{44}^E & 0 & 0 \\ 0 & 0 & 0 & 0 & s_{55}^E & 0 \\ 0 & 0 & 0 & 0 & 0 & s_{66}^E = 2(s_{11}^E - s_{12}^E) \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} + \begin{bmatrix} 0 & 0 & d_{31} \\ 0 & 0 & d_{32} \\ 0 & 0 & d_{33} \\ 0 & d_{24} & 0 \\ d_{15} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

$$\begin{bmatrix} D_1 \\ D_2 \\ D_3 \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & d_{15} & 0 \\ 0 & 0 & 0 & d_{24} & 0 & 0 \\ d_{31} & d_{32} & d_{33} & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} T_1 \\ T_2 \\ T_3 \\ T_4 \\ T_5 \\ T_6 \end{bmatrix} + \begin{bmatrix} \epsilon_{11} & 0 & 0 \\ 0 & \epsilon_{22} & 0 \\ 0 & 0 & \epsilon_{33} \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

- Simplified to one dimension

$$\begin{aligned} S_1 &= s_{11}^E T_1 + d_{31} E_3 \\ D_3 &= d_{31} T_1 + \epsilon_{33}^T E_3 \end{aligned}$$



# Typical Material Constants

PZT 5H (Navy Type VI)

$d_{31}$ (m/V)	$d_{33}$ (m/V)	Elastic modulus (N/m <sup>2</sup> )	Density (kg/m <sup>3</sup> )	$\epsilon_{33}^T$ (F/m)	Curie temp (°C)
$-320 \times 10^{-12}$	$650 \times 10^{-12}$	$6 \times 10^{10}$	7800	$3.36 \times 10^{-8}$	230

$$+ \begin{bmatrix} 0 & 0 & d_{31} \\ 0 & 0 & d_{32} \\ 0 & 0 & d_{33} \\ 0 & d_{24} & 0 \\ d_{15} & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} E_1 \\ E_2 \\ E_3 \end{bmatrix}$$

$$d_{33} \sim 2 \times d_{31}$$

Since E is scaled by distance (V/m) field applied across thin dimension

# Common Configurations

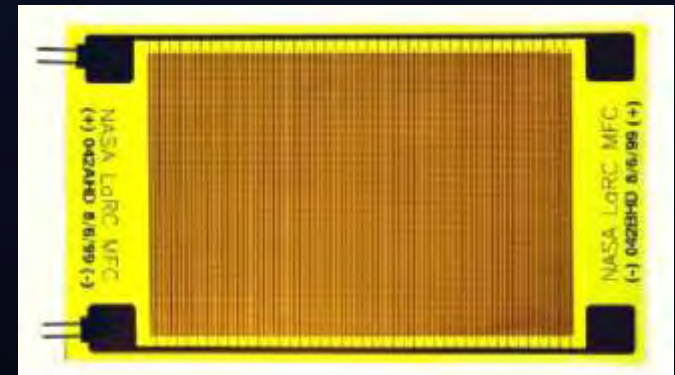
- Patch
  - Generates /responds to plate and beam bending and tensile/compressive waves
  - Unimorph and bimorph configurations
- Stack
  - Takes advantage of  $d_{33}$  coefficient
- MFC
  - Uses  $d_{33}$  coefficient for in-plane motion



Stack actuators from APC International  
[www.americanpiezo.com](http://www.americanpiezo.com)



Patch actuator



MFC actuator

# Piezo Sensing/Actuation Examples



## Sensing

- Accelerometer
- Power harvesting
- Passive damping – shunting (skis)



## Actuation

- Atomic force microscope position control
- Speakers
- Buzzers
- Anything “ultrasonic” (humidifiers, cleaners)
- Depth finders/SONAR



## Sensing/ actuation

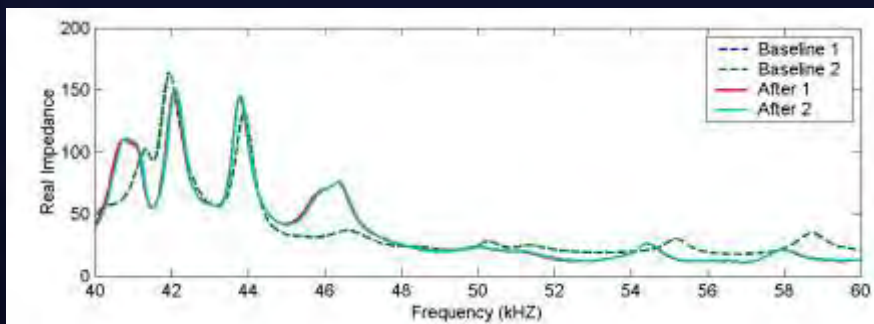
- Structural monitoring
- Vibration control

## Current Fuzing Applications

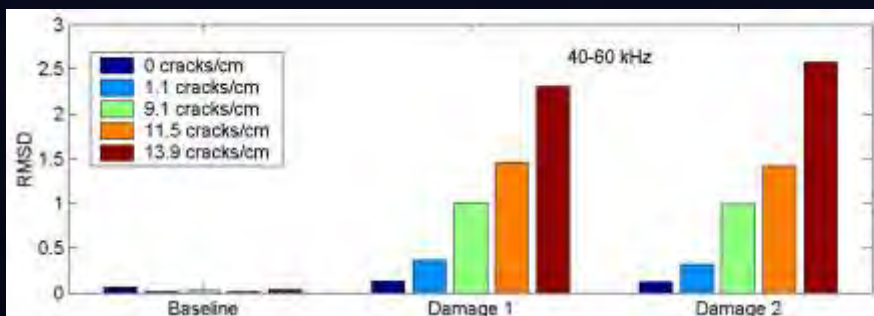
- Dozens of piezoelectric fuze patents
- Rocket Propelled Grenade
  - Acceleration at launch strains **piezoelectric fuze** that ignites primer.

# Piezo-Based SHM

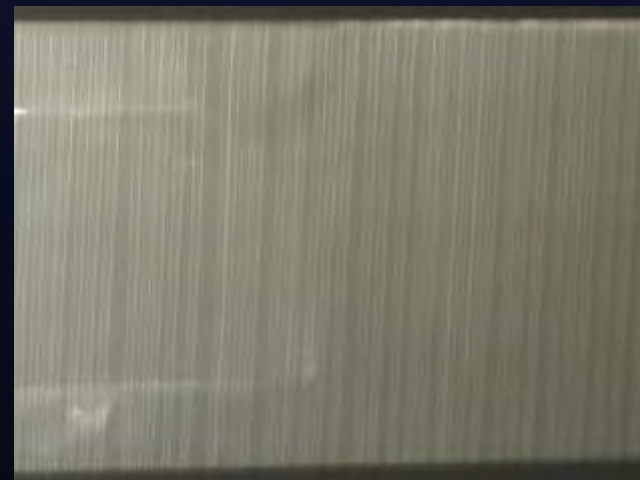
- Utilizes high frequency vibrations to detect local changes in materials
  - *Stiffness changes due to cracking*
  - *Increases in damping*
  - *Interface changes such as loosening of a joint.*
- Electrical impedance is directly related to mechanical impedance
- Wave propagation approach can also be utilized
  - *Measure reflections, attenuation, delay due to damage*



Impedance response



Damage Metric

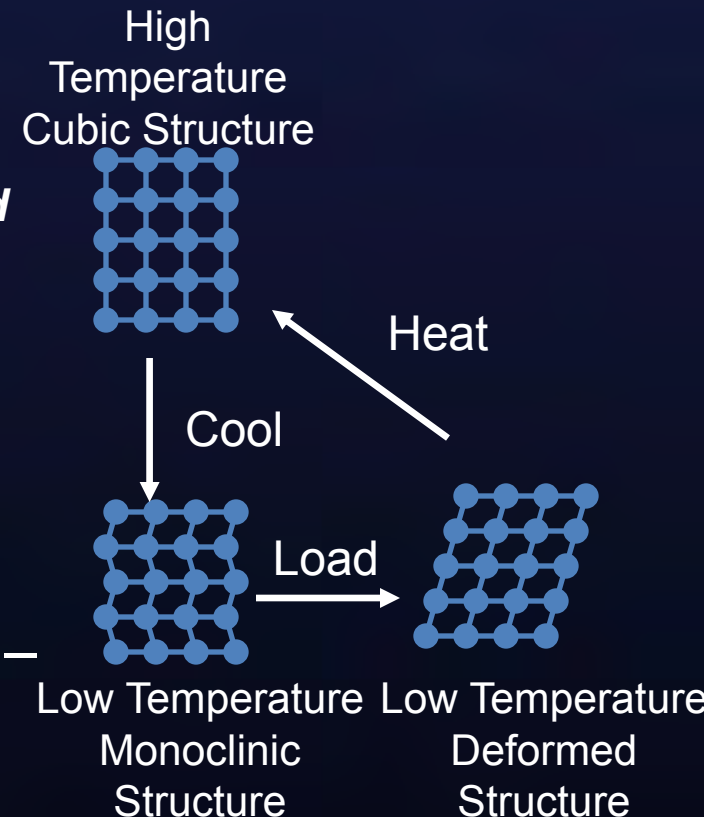


Matrix cracking in carbon fiber composite



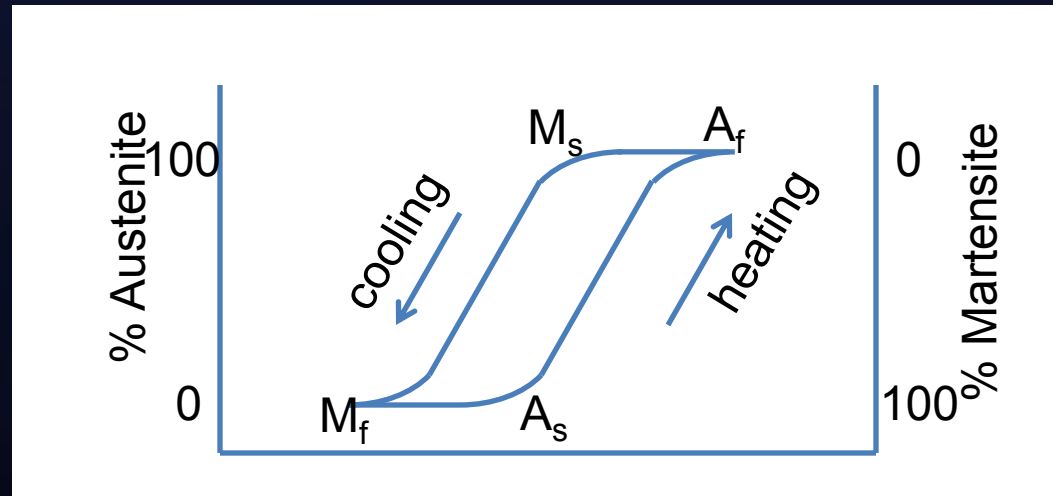
# Shape Memory Alloy

- NiTiNOL developed at Naval Ordnance laboratory
- Shape memory effect : result of change in crystal structure
  - *Martensite at low temperature- twinned crystal structure*
  - *Austenite at high temperature- body centered cubic*
  - *Reverts to original undeformed shape when heated beyond transition temperature*
  - *One-way and two-way effects*
- Stress can also cause transition – Superelastic effect
- 6-8% strain
- Relatively slow response time
  - *Speed increased for low volume (faster temperature change)*



# Temperature Transition

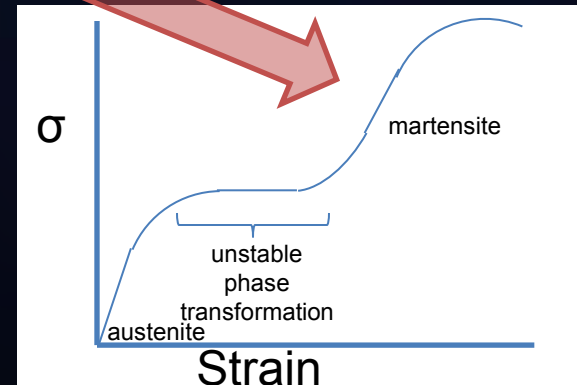
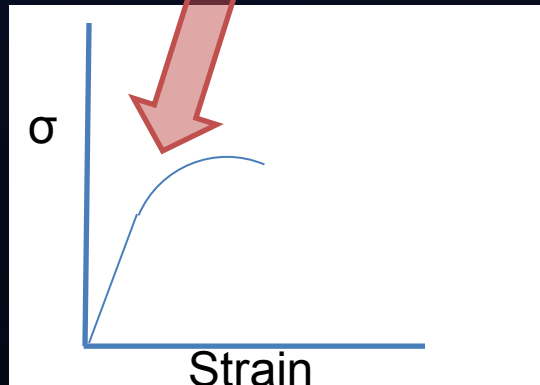
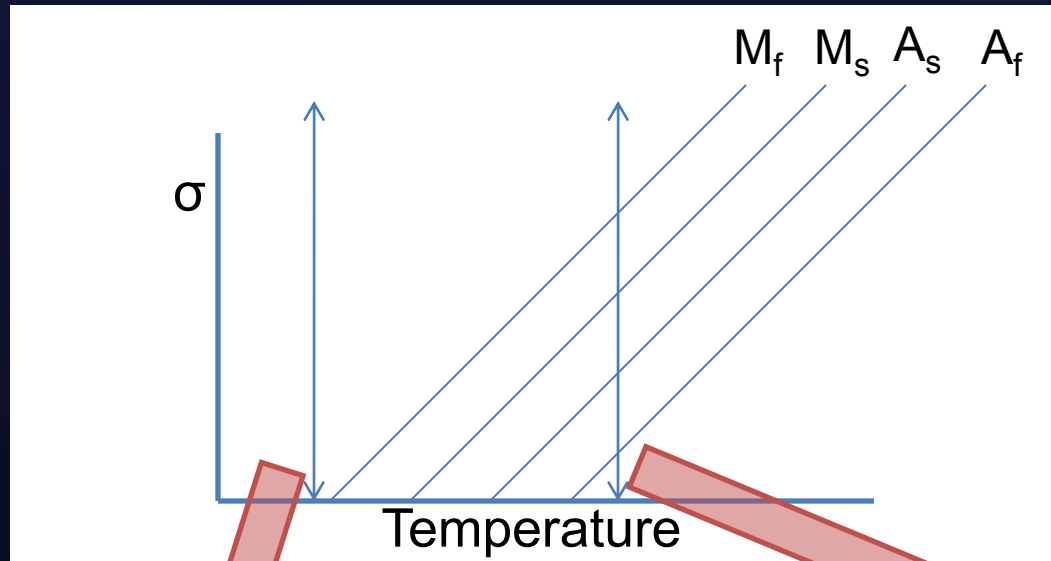
- Width and temperature of hysteresis can be controlled
- State dependent on path to current temperature





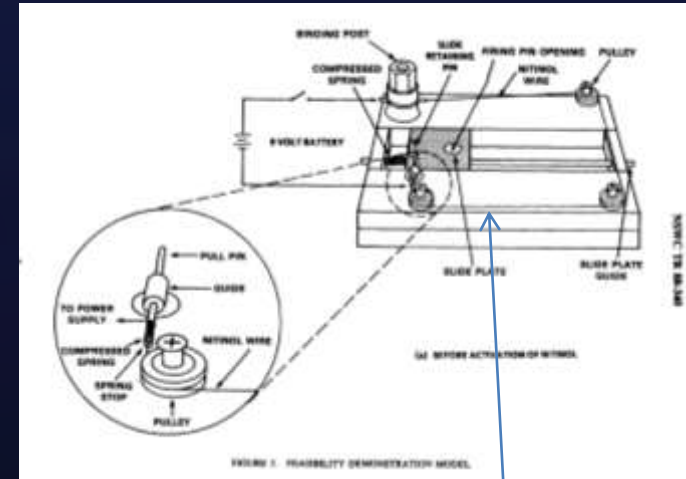
# Superelastic Behavior

- Stress-strain curve depends on material temperature relative to transition temperature



# SMA Fuzing Examples

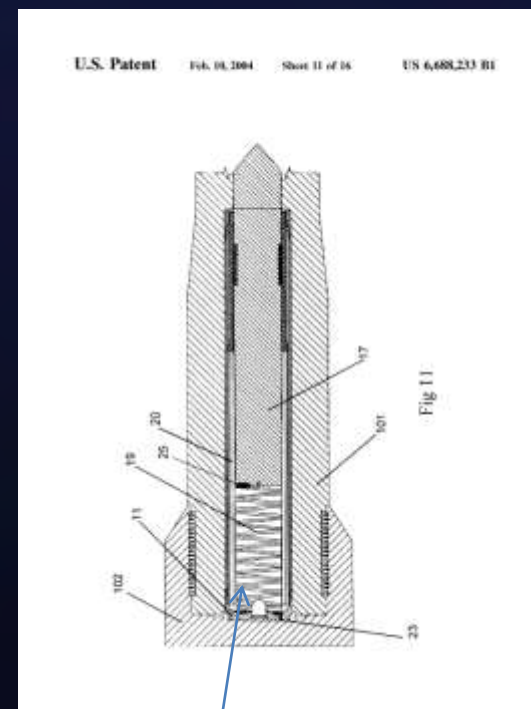
- Damping
- S&A actuation
  - *Goldstein and Weiner*
  - *Investigated effects of prestrain on transition temperature*
    - Activation temperature up to 150 C
- Non-pyrotechnic separation systems
- IM compliance
  - *Marchand et al. - Mine Clearance System rocket-towed linear demolition charge makeover*
  - *SMA proposed for release rocket motor case at both ends and actuate thermal igniter for Slow-Cook mitigation*
- Manufacturing
  - *Removable fixturing*



SMA wire

# Reusable SMA Projectile Translation

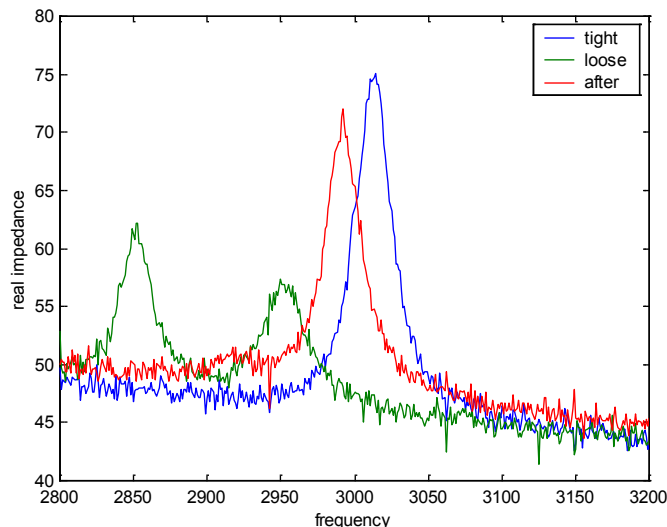
- Recoil, launch stress can be reduced by translating projectile a small distance forward prior to launch
- Typically accomplished by secondary charge
  - *Not reusable if launch is aborted*
- SMA spring suggested for Cased Telescoped Ammunition
- Manole et al. 2004 US patent 6,688,233B1



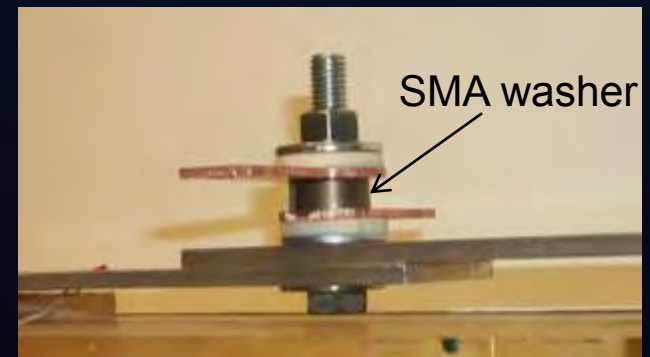
SMA spring

# Self-Healing Bolted Joint

- Proof-of-concept testing
- Heated with external heater or resistively
  - *Competing for electrical and thermal isolation and high stiffness*
- Joint tightness monitored with PZT
- SMA ring sized to provide tension to compensate for reduced torque tightening



Impedance response of joint

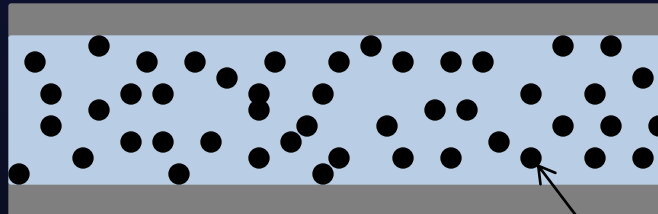




# Magnetorheological (MR) Fluids

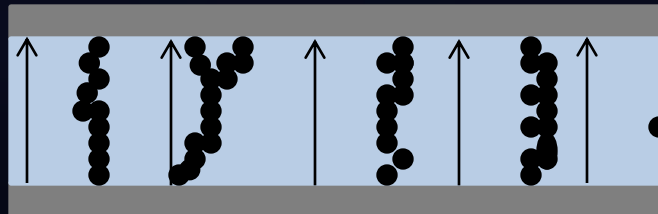
- Change viscosity with magnetic field
- Response times on order of 10 ms
- Viscoelastic solid below yield stress when field applied
  - *Field dependent modulus*
- Newtonian fluid when field is off

No magnetic field



ferromagnetic particles

Magnetic field present



# Possible Fuze Application

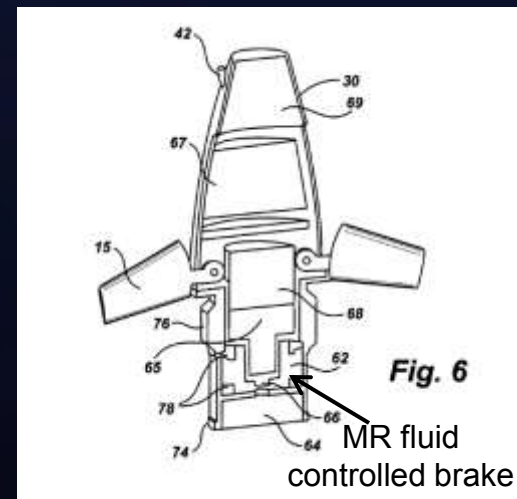
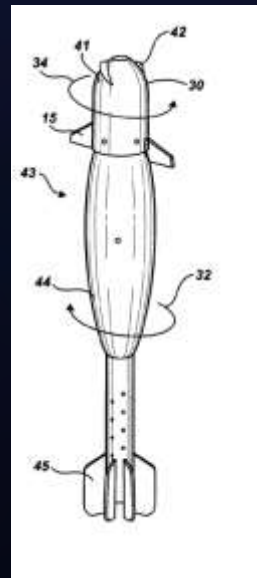
- Research on self-regulation of delay arming time of MR fluid fuze (Hu et al. 2010, Jiaxing University and Nanjing University of Science and Technology)
  - *Permanent magnet used to keep MR fluid as a solid during storage*
  - *Setback causes magnet to separate and rod impacts a piezo energy harvester*
  - *Energy harvester charges capacitor*
  - *Capacitor discharges into coil to regulate MR fluid viscosity*
  - *MR fluid viscosity controls flow through an orifice to control arm time*





# MR Fluid Braking

- Morris et al., US Patent 7354017, 2008, Projectile trajectory control system
- Used to control de-spin of a projectile with braked rotating fins.



# Summary and Conclusions

- Smart Materials offer alternative sensing and actuation systems
  - *Piezoelectric materials provide both sensing and actuation at high speed and forces, but low displacement*
  - *SMA provides high displacement and forces, but low speed*
  - *MR fluid provides fast response time and relatively high forces*
- Numerous unexplored applications for these materials exist including in the fuzing and ordnance environment





# ***Course Correction Fuzes Integration Technologies***

***55<sup>th</sup> Annual Fuze Conference  
"Fuzing's Evolving Role in Smart Weapons"***

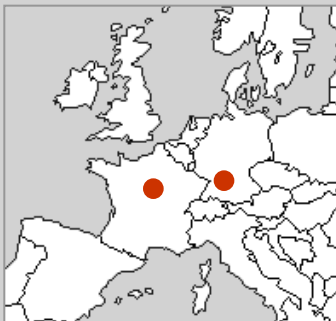
***Salt Lake City, UT - May 24-26, 2011***

**Max Perrin  
JUNGHANS Microtec**

- Course Correction Fuze – Main technology issues
- Main functions
- Technology evolutions and technical challenges
- Example of current Course Correction Fuze programmes
- Integration solutions for 1D-CCF
- Future trends
- Conclusion

# Company Presentation

- A leader in the field of ammunition fuzes and S&A devices
- Full range of products
- Key competences in
  - Fuzing technologies
  - Micro-technologies
  - Ammunition electronics





# Course Correction Fuzes

## Main Technology Issues

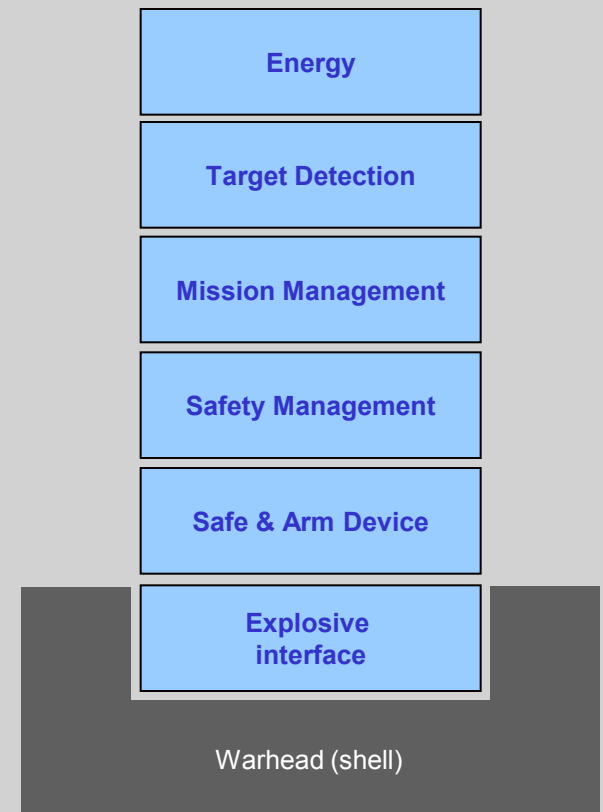
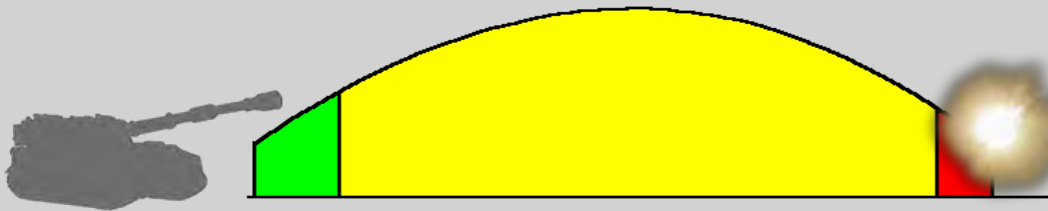
- Standard fuze size
  - Fitted on conventional munitions
- Additional functionalities and performances, in a fuze envelope
  - Fuzing functions (MOFA type)
  - + Course correction functions
    - Electronics and guidance device
- Gun environment
  - Ramming / Firing
  - Standard interfaces with weapon systems
  - Data link with weapon system
    - Before flight / during flight





# CCF – Main Functions

- Fuzing functions and modules
  - Safety
    - Safety environment sensors + safety management + firing train interruption
  - Mission management
    - Data-Link with weapon, before and/or in-flight (mission parameter programming)
  - Target detection :
    - Sensors + processing + triggering decision
  - Warhead initiation
    - Firing train + interfaces



# CCF – Main Functions

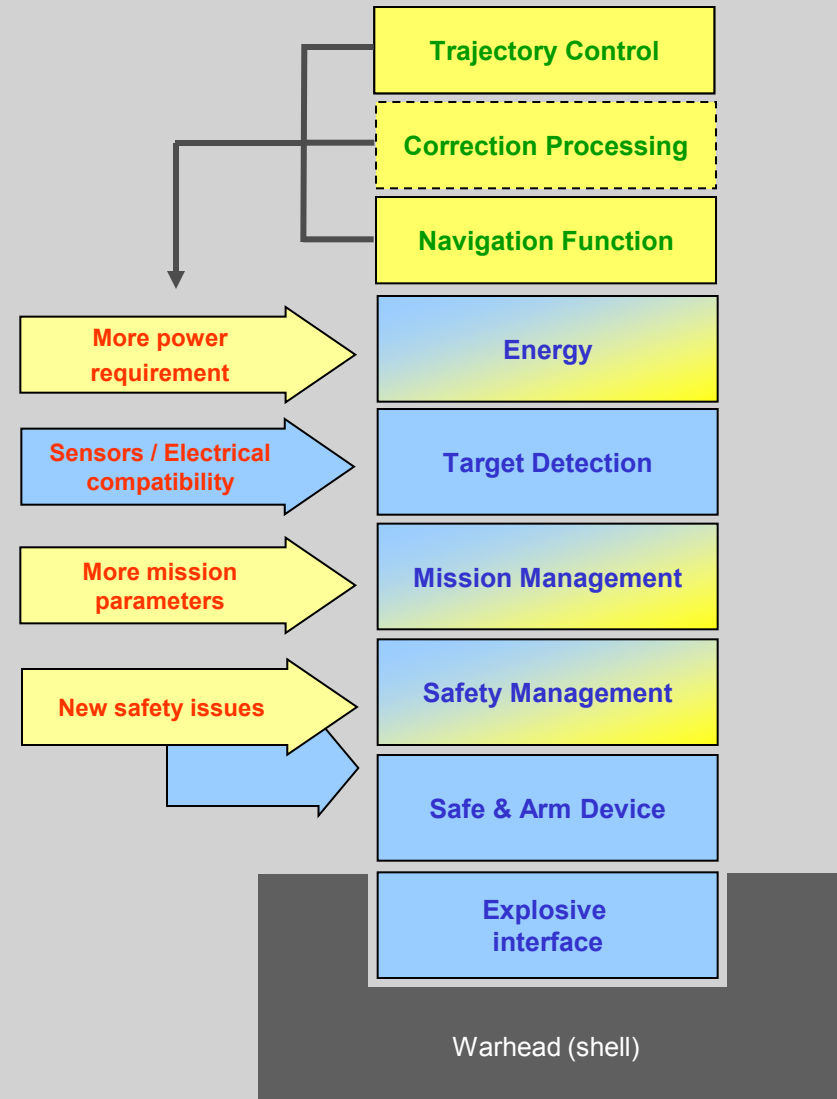
- Fuzing functions

+

- Course Correction Functions

- Navigation Function: trajectory estimation
- Correction Computing: algorithm + processor
  - Fuze embedded processing
  - or Weapon system processing
- Trajectory Control: air control device + actuators

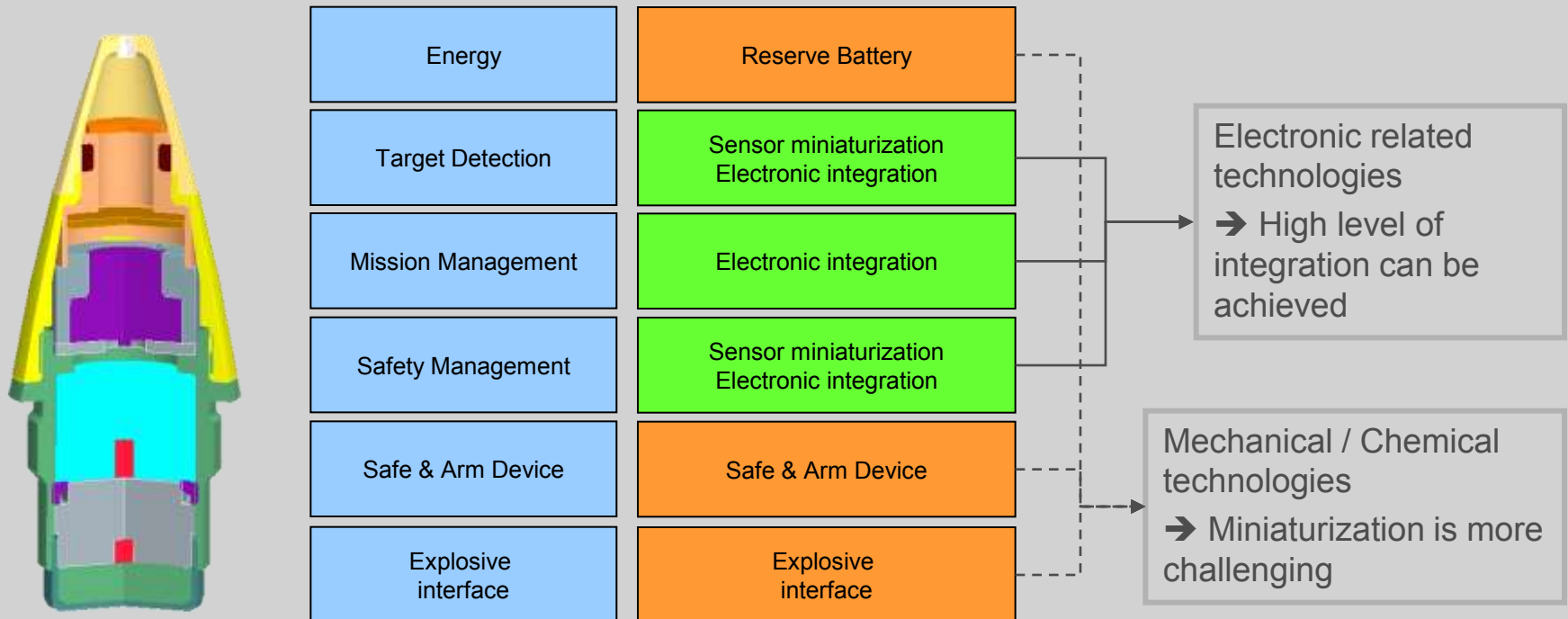
- The implementation of these functions has an impact on the requirement and the design of the fuze's other functions



# Technology Evolutions

## Fuzing Functions

- Fuzing functionalities and capabilities have been significantly improved due to the electronic and sensor technology evolution (dual use components)
  - More versatility, operational flexibility, target detection performance  
→ Multifunction fuzes
- Difficult to get the same technology progress with non-electronic and specific fuze modules



# Technology Evolutions

## Course Correction Functions

- Implementation of Course correction functions
  - Require significant space in the standard fuze architecture
  - Use various technologies which cannot be highly integrated



Trajectory Control	Drag brake device Actuators
Correction Processing	Digital processor integration
Navigation Function	Antenna (GPS or Receiver) Electronic processing / integration Inertial Measurement solutions
Energy	Reserve Battery
Target Detection	Sensor miniaturization Electronic integration
Mission Management	Electronic integration
Safety Management	Sensor miniaturization Electronic integration
Safe & Arm Device	Safe & Arm Device
Explosive interface	Explosive interface

Physical constraints and requirements

➔ Miniaturization difficulties, and relevance ?

Specific integration issues

Electronic technologies

➔ High level of integration can be achieved

# CC Fuze Development

## Main Technology Challenges

- Main objective: Low-risk – low-cost design approach
  - Leverage in-service modern fuze design
  - Use existing qualified components
- Main challenges
  - Comply with the standard fuze size: STANAG 2916 contour / short intrusion
  - Re-use available sub-assemblies, in their current design
  - Optimise the integration for some of the fuze functions to provide space for the additional course correction functions
  - Cope with available (autonomous) power supply
  - Deal with compatibility issues between the different technologies living together in a small space, in particular:
    - Electromagnetic compatibility and interference issues within the various electronic circuits
    - Various antenna type integration, for different purposes, inside the fuze envelope

# CC Fuze Development

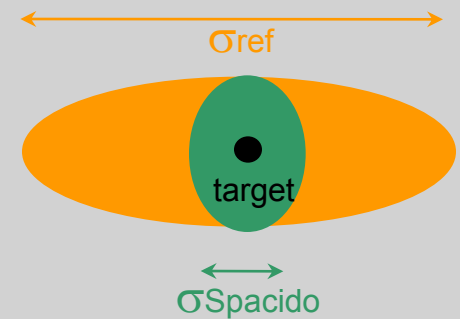
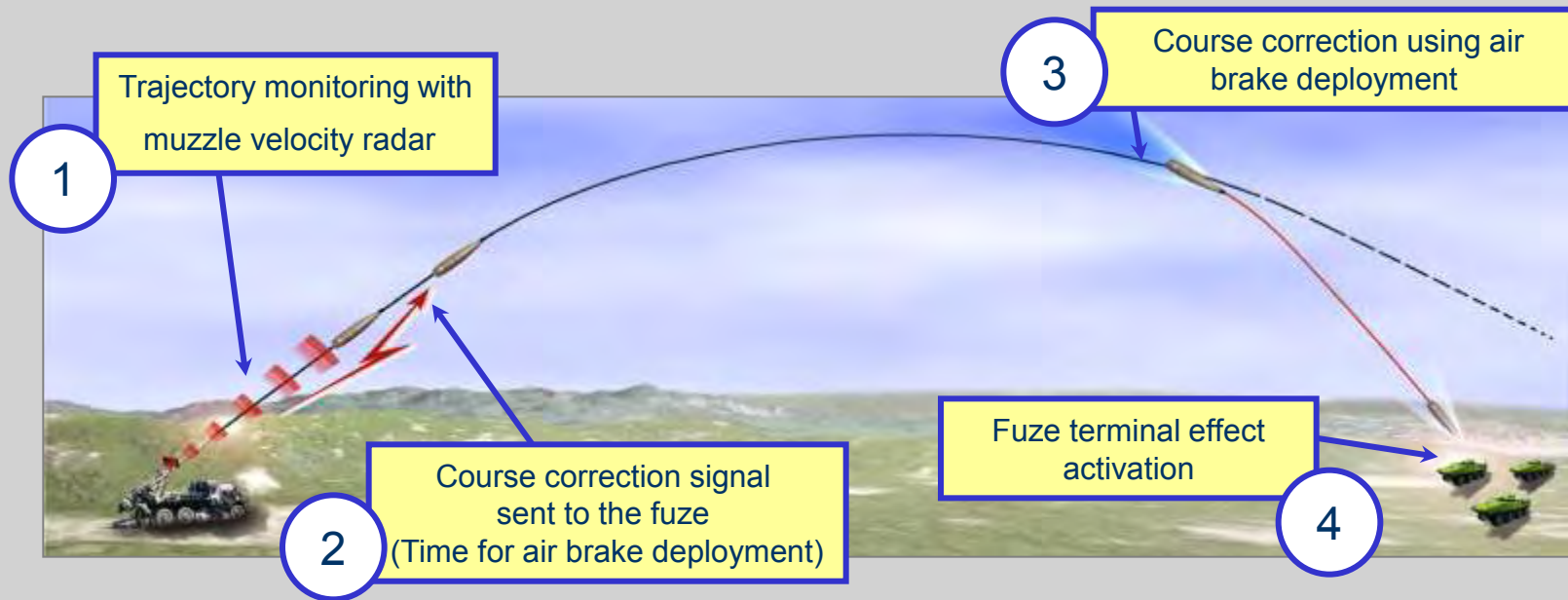
## Example of current CCF programmes

- JUNGHANS is today implementing integration solutions in major course correction fuze programmes carried out in Europe
  - Relying on modern multifunction fuze architecture and proven modules and components
- Two concepts based on different navigation and localization solutions:
  - very different concept and design
  - different integration problems and solutions
- **SPACIDO Fuze**: in co-operation with NEXTER, France
  - "Non-GPS" trajectory navigational system solution  
Trajectory estimation based on the projectile initial velocity measurement by the muzzle velocity radar (MVR)
  - Range correction order sent to the fuze by the MVR
- **ECF (European Correcting Fuze)**: in co-operation with BAE Systems, UK, (GCSM) and Sweden (GCSW)
  - GPS based solution
  - Trajectory estimation based on the use of GPS C/A receiver





# SPACIDO System



• In cooperation with

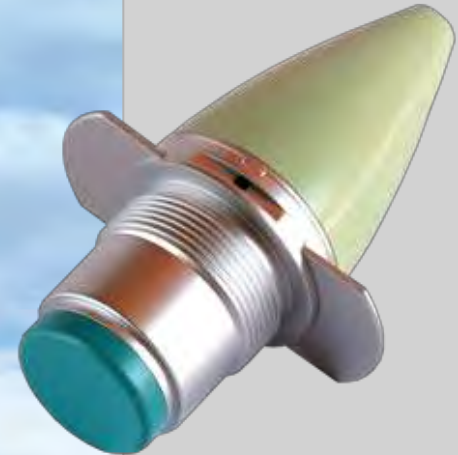
**nexTER**  
MUNITIONS

# Fuze Integration Technologies

## Course Correction Fuze

# ECF (European Correcting Fuze)

**JUNGHANS**  
*microtec*

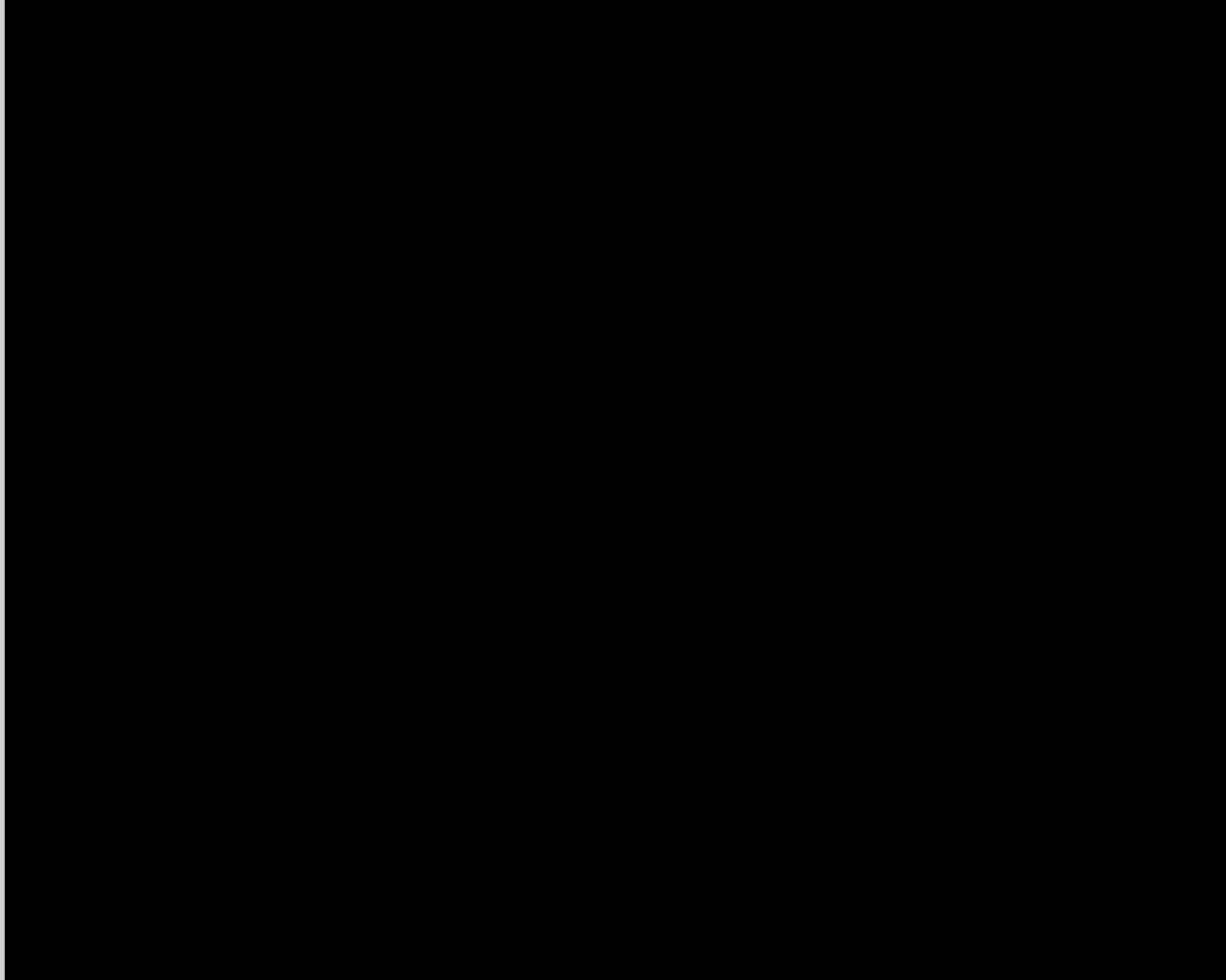


• In cooperation with

**BAE SYSTEMS**

A Diehl and Thales Company

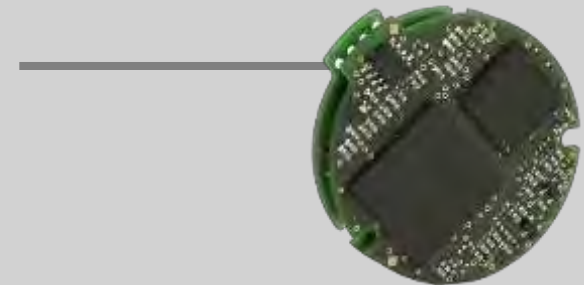
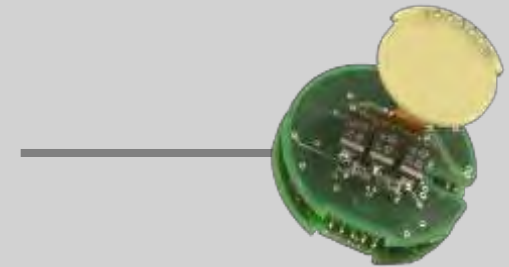
ECF



# Integration Solutions for 1D-CCF

## Basic Options

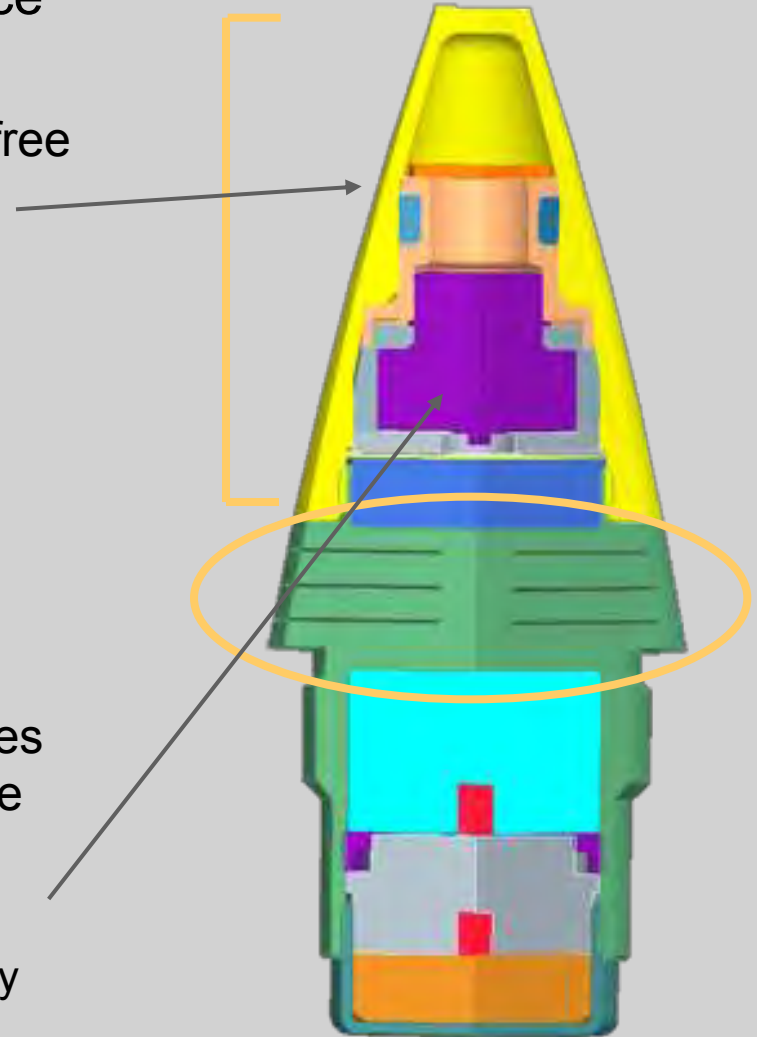
- Re-use proven sub-assemblies, as they are
  - Reserve battery - Lithium
  - Mechanical Safe & Arm Unit
  - Even if they are bulky items,
  - ➔ More cost effective and less risky
- Re-use target detection device (HoB sensor)
  - ➔ Slight adaptation to cope with space compatibility with other electronic boards, but same design
- Share the processing unit between target detection signal processing and correction processing
  - ➔ Select suitable component to cope with computation power requirement





# Integration Solutions for 1D-CCF

- 1D-CCF are fitted with drag brake device located in the central part of the fuze
  - Benefit: The nose cone of the fuze is free for antenna and radome integration
    - SPACIDO: Data-link receiver with antenna
    - ECF: GPS receiver and antenna
- Power requirements for 1D-CC
  - Aerodynamical control devices do not need high power actuators
  - Functioning of the various fuze modules and related power consumption can be managed all along the flight
    - Benefit: The power requirement is compatible with current reserve battery features

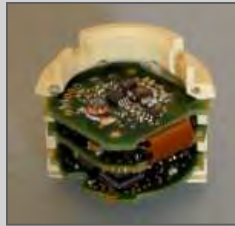




# Integration Solutions for 1D-CCF

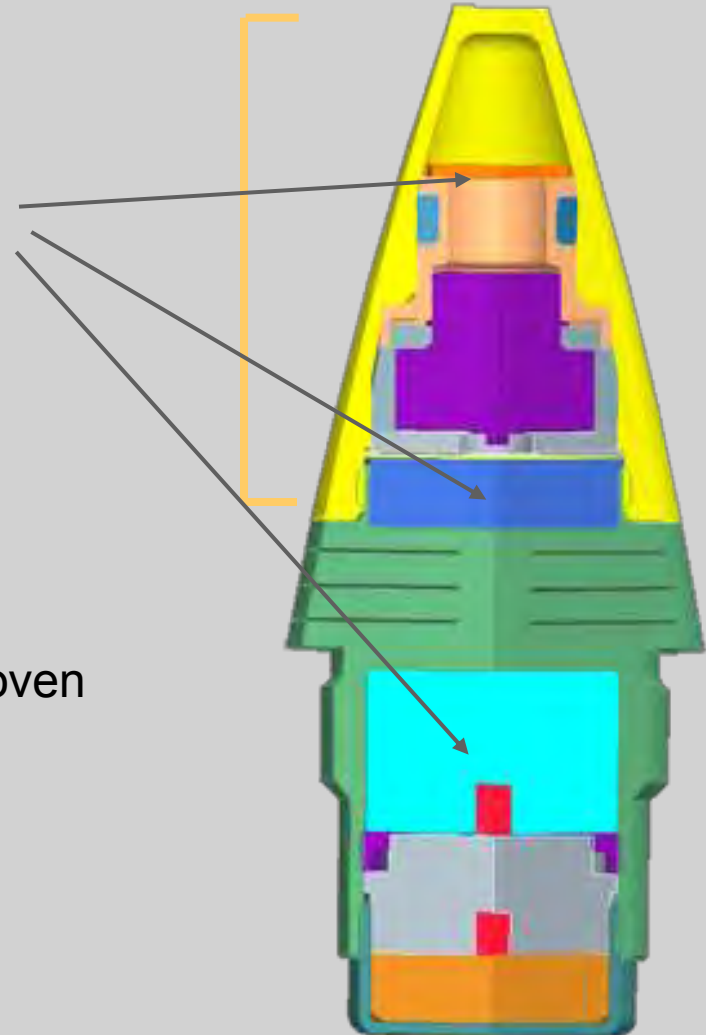
- Board interconnection techniques

- More constraints: numerous boards, more data, no space available for connections, testing requirements
- Optimized architecture to reduce interconnections
- Flexprint circuits



- G-hardening

- Possibility to keep and implement proven techniques from modern electronic artillery fuzes
  - Fuze frame design
  - Electronic board design
  - Potting material and techniques



# Integration Solutions for CCF

## Antenna Integration

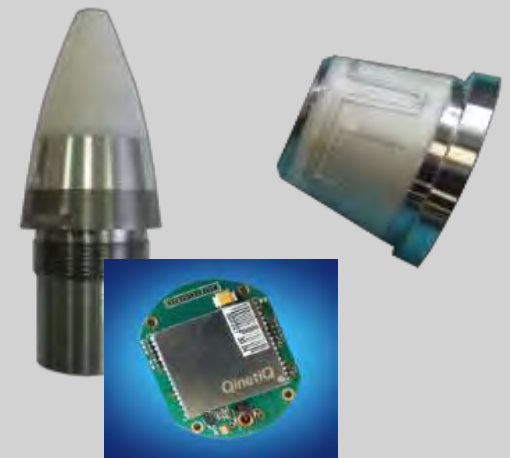
- SPACIDO

- Integration of an embedded data-link receiver
  - receiver / decoder board
  - with "looking backward" antenna
- Compatible with other modules requiring external access
  - STANAG 4369 programming coil
  - HOB sensor antenna and signal processing board



- ECF

- Integration of an embedded GPS receiver
  - GPS receiver board
  - with antenna (revolution symmetric radiation pattern)
- Compatible with other modules requiring external access
  - Programming interface for high-rate data transmission
  - HOB sensor antenna and signal processing board



# Other integration issues and technology solutions

- Interference problems between the different electronic modules operating in a very close vicinity

- Converters, processors, oscillators, etc



No room for physical shielding: Therefore the design requires very fine optimization (PCB layout, circuit frequency selection)

- Data-link for fuze programming before flight

- Low rate or high-rate depending on the required mission parameters (Fuzing parameters, GPS ephemeris, etc..)



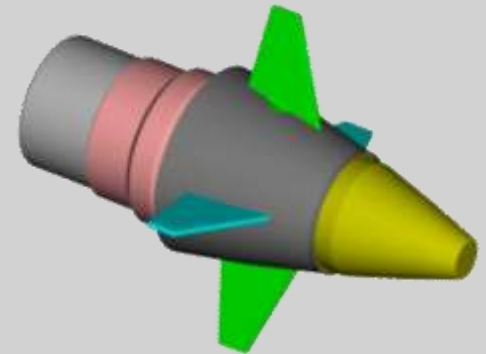
Optimization of the communication protocol to lower hardware and software constraints

- ... and always

- Keep good reliability
- Keep high level of survivability to harsh conditions created by gun firing
  - High-G hardening on new technologies

# Trends for guidance integrated fuzes

- Integration of future CCF concept or guidance integrated fuzes:
  - Much more tricky issue to keep all functions fitted into a standard short intrusion fuze envelope
  - Difficult to re-use conventional fuze components
- Some new challenges:
  - Guidance solutions
  - Navigation, incl. Inertial Measurement
  - New safety issues for the artillery systems
  - High-G hardening of new technology devices
- Some technological breakthrough will be required to meet the requirements in terms of:
  - Miniaturization, cost, reliability, safety for such products



- Course Correction Fuze development has created significant technical challenges to the fuze designer who has now to integrate new functionalities in the same fuze envelope
- Thanks to the progress achieved in electronic technologies but also in the fuze integration techniques, it is now possible to design smart fuzes featuring significant functionalities, including course correction capability
- JUNGHANS has taken on the technological challenges and has implemented solutions
  - To provide the user with smart fuzes, but still affordable and reliable
  - To prepare the technological breakthrough required for future fuze generation



# Thank You

**Max PERRIN**

**Chief Technical Officer**

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**[max.perrin@junghans-t2m.fr](mailto:max.perrin@junghans-t2m.fr)**





# ***Fuze for Tiger Helicopter Rocket Inductive Setting and Motor Ignition***

***55<sup>th</sup> Annual Fuze Conference  
"Fuzing's Evolving Role in Smart Weapons"***

***Salt Lake City, UT - May 24-26, 2011***

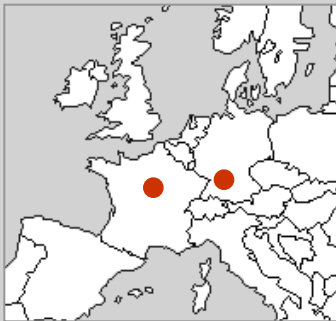
**Max Perrin**  
**JUNGHANS Microtec**

# Outline

- Tiger Rocket system
- Operational Issues
- Fuzing Solutions
- *METAE* Fuze – Inductive setting
- *METAE-AI* Fuze – Inductive setting + motor ignition
- Future developments

# Company Presentation

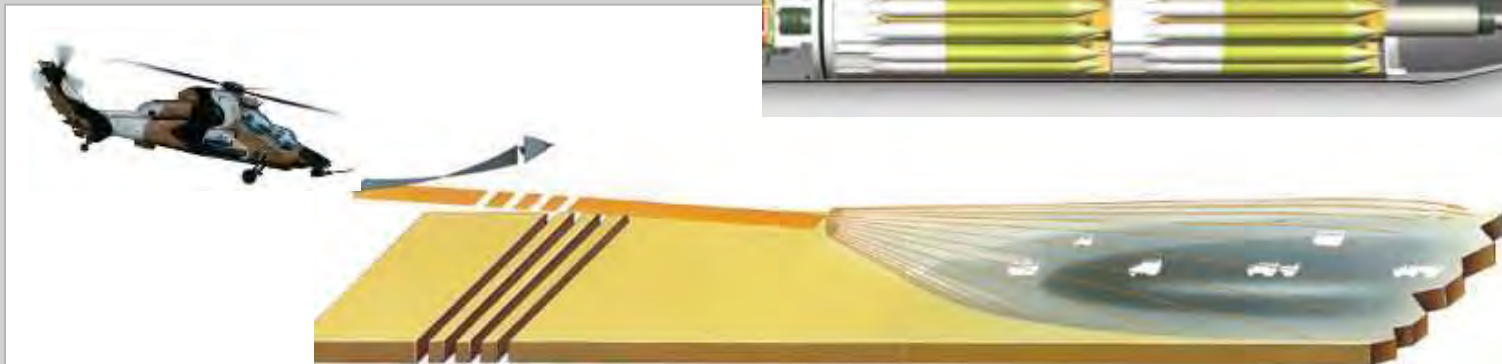
- A leader in the field of ammunition fuzes and S&A devices
- Full range of products
- Key competences in
  - Fuzing technologies
  - Micro-technologies
  - Ammunition electronics



# Rocket System for Attack Helicopter

## Anti-vehicle Flechette Warhead Concept

- The efficiency of air-to-ground rockets fitted with a flechette warhead has been proven in the past as well as in today's conflicts
- Basic features
  - Used against light armored targets
  - Contains a large number of small arrow-shaped projectiles (darts)
  - Target damage caused by the kinetic energy of the flechette
  - Flechette dispensing controlled by a programmable time fuze
  - Various dart size available for different target / terminal effect
- The projectile dispersal concept compensates
  - the target's movements
  - the inaccuracy around the point of impact



# French Tiger Helicopter Rocket System

- Today the French Tiger Helicopter is fitted with the most modern rocket system. This system relies on 68mm caliber rockets
- It is currently in service in operational theaters
- The 68mm Rocket System is designed and produced by TDA Armements, France



## 68 mm System



22 Rocket Pod



12 Rocket Pod



Weapon Interface Management System



Flechette Warhead



Training Smoke Warhead



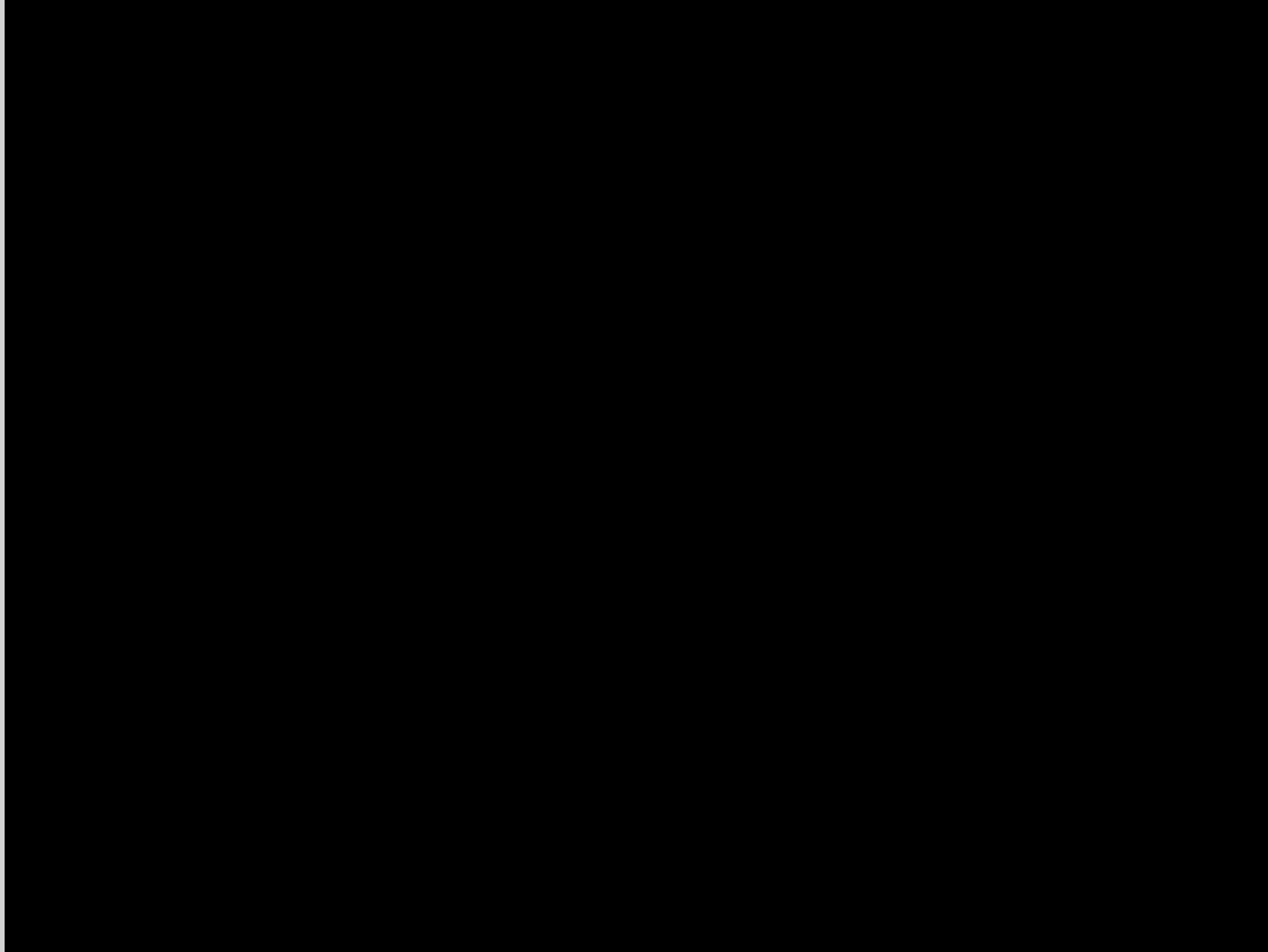


# 68mm Rocket System on Tiger



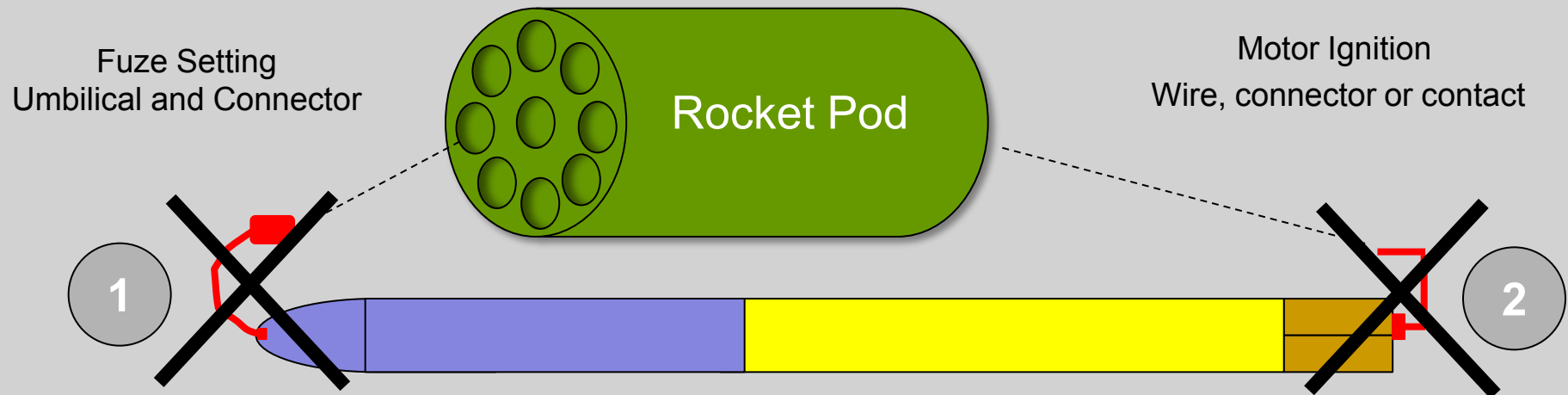


# Video – Rocket System



# 68mm Rocket System - Main Objectives

- Provide benefits to the user in terms of
  - Logistics – Maintenance – Reliability – Safety
- By removing any wire or contact connection between the launcher and the rocket
- Solution: Achieve fuze setting and motor ignition with wireless techniques
  - The 68mm Rocket System features this technique with a new generation electronic fuzing system



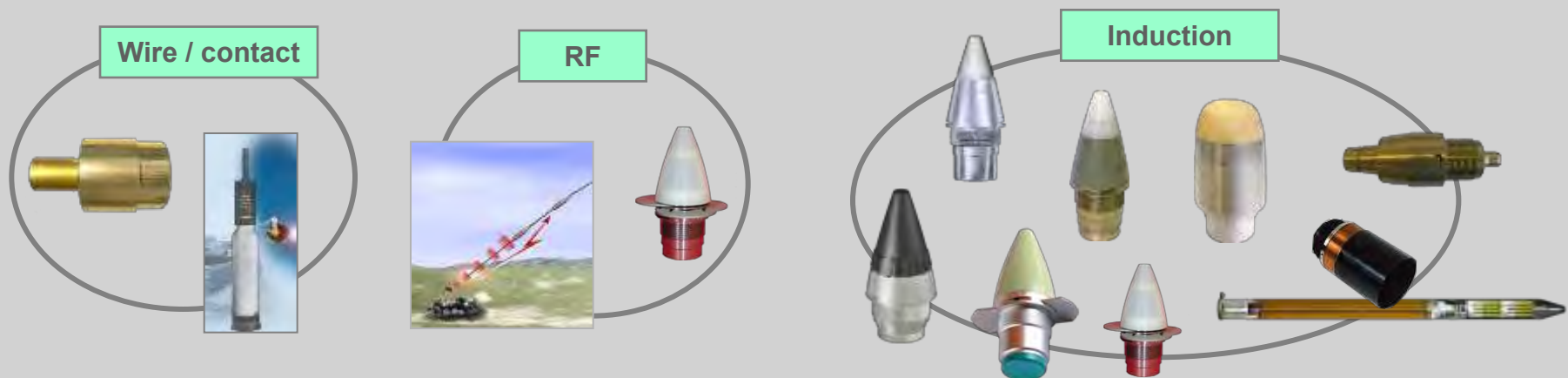
# Operational Issues related to wire connecting

- Fuze setting and motor ignition with conventional solutions, based on wire or contact link, lead to significant operational constraints and problems:
  - Scattered scraps generated when firing the rockets (cables, connectors)
    - Safety issue if debris damage the helicopter body or controls
  - Long loading time of rocket in pods
    - Connection to be carried out for each rocket
  - Wire and connectors weaknesses
    - Possible clogging up of connectors and contacts
    - Loose connections
  - Watertightness issues
  - EMC issues








# METAE and METAE-AI new generation fuzes

- Wireless fuze setting solutions developed by JUNGHANS have provided new generation rocket system with unmatched operational flexibility, safety and reliability
  - METAE fuze: Inductive setting.
    - Qualified and produced from early 90's onwards
    - Qualified on Tiger helicopter in 2000
  - METAE-AI fuze: Inductive setting + inductive motor ignition
    - Qualified in 2010, Serial production started early 2011
- JUNGHANS background in fuze setting / communication techniques



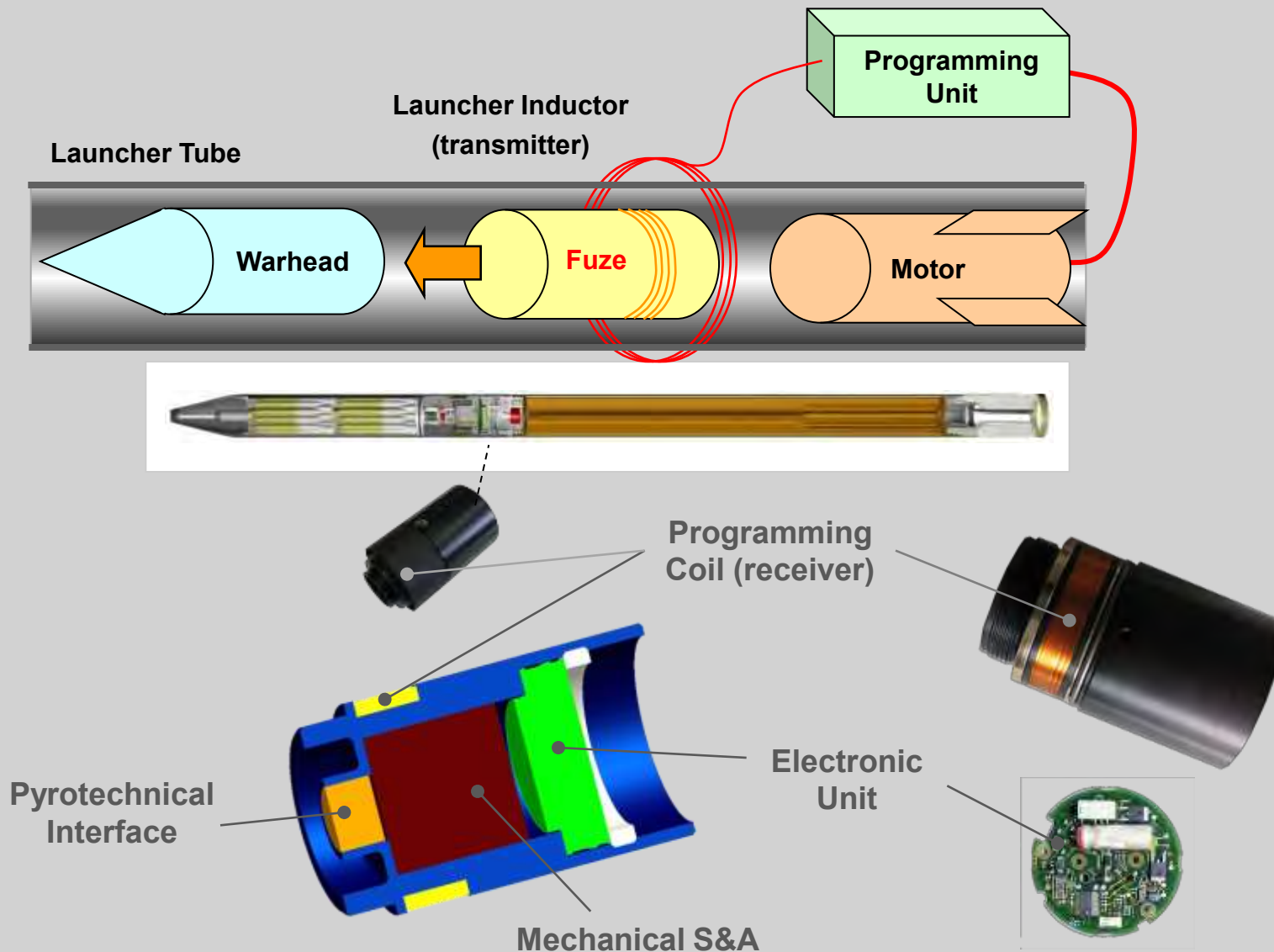
- Main technical challenges

- Inductive link through metallic launcher tube 
- Multiple tube launcher 
- Fuze power supply 
- Fuze electronics power consumption 
- Data transmission safety 

- METAE Fuze solutions

- Selection of the good compromise for
  - suitable metal material for the tube
  - thickness of the tube
  - frequency of the carrier signal for data linkto deal with inductive transmission issues
- No internal battery
  - Energy provided by the fuze setting unit and transferred at setting phase, prior to firing
- Use of safe communication protocol

# METAE Fuze – Inductive Programming

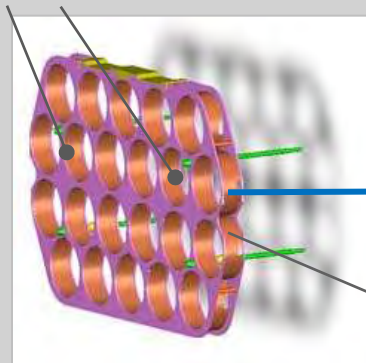




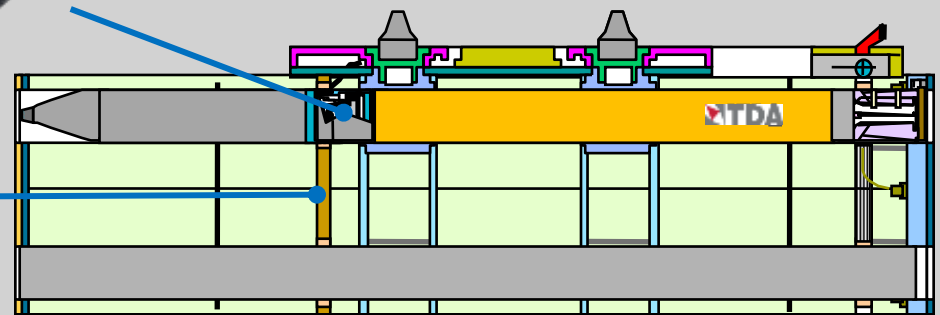
# METAE and METAE-AI Fuzes Launcher integration



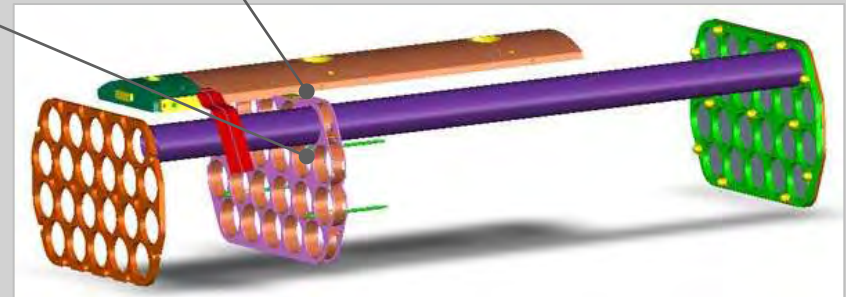
Launcher  
Inductors



Fuze

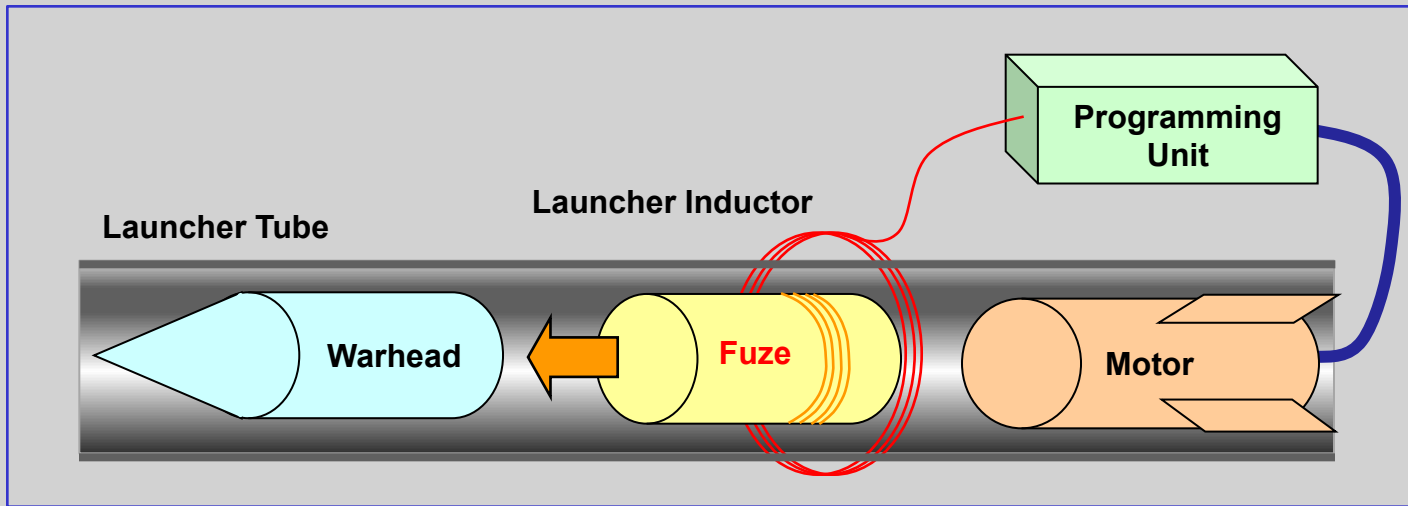


Integration  
in the 22  
rocket pod



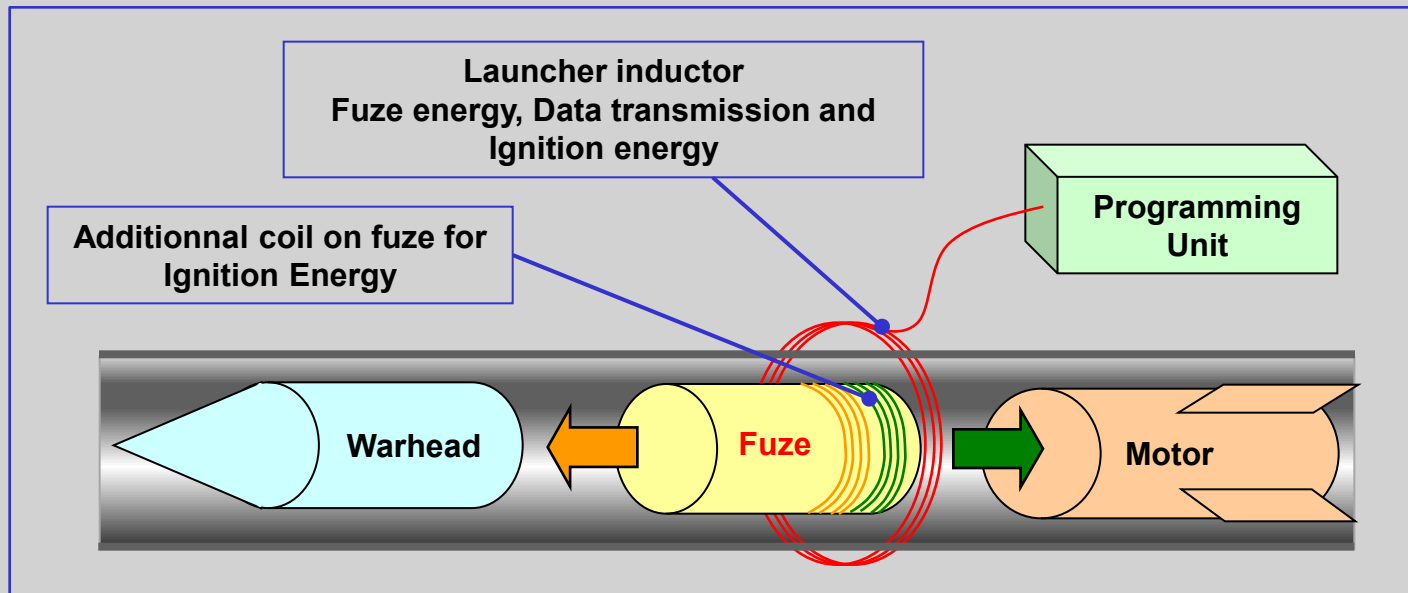
- Inductive fuze setting
  - Data transmission, electronic energizing and energy transfer
  - Fuze setting carried out just before firing
  - Message duration: 35ms
  - Manchester encoding
- Programmable flight time
  - From 1.28s to 30s
- Power supply
  - Energy transfer at inductive programming
  - Energy storage by capacitor
- Digital electronics
- Safety distance
  - Mechanical S&A unit: 0.7s arming delay

# METAE-AI Fuze – Programming + motor ignition



## METAE Fuze

Inductive Programming  
+  
Contact / connection  
for motor ignition



## METAE-AI Fuze

Inductive Programming  
+  
Inductive Motor Ignition

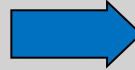
# METAE-AI Fuze – Main Features

- Fuze setting:
  - Same as the METAE fuze
- Fuze features
  - Same as the METAE fuze
- Motor ignition
  - No contact nor connection with the launcher
  - Fully controlled by the fuze
  - Dual coil to transmit suitable ignition energy
  - Motor ignition carried out just after message transmission
  - Ignition signal generated when two conditions are met
    - Decoding of the correct message and flight time
    - Checking that the required ignition energy is available

# METAE-AI Fuze

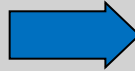
## Summary of Operational Benefits

- No wire - no connector



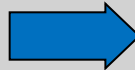
- Reduced time for maintenance
- Reduced time for loading operation
- Enhanced reliability

- No scattered scrap and debris when firing



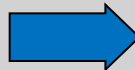
- No damage to helicopter
- Enhanced safety

- Qualified in severe EMC environment



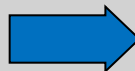
- Enhanced safety
- Enhanced reliability

- Digital electronics



- Enhanced precision
- Enhanced operational flexibility
- Growth potential for new weapons

- No external access / induction protocol needed to activate motor or fuze

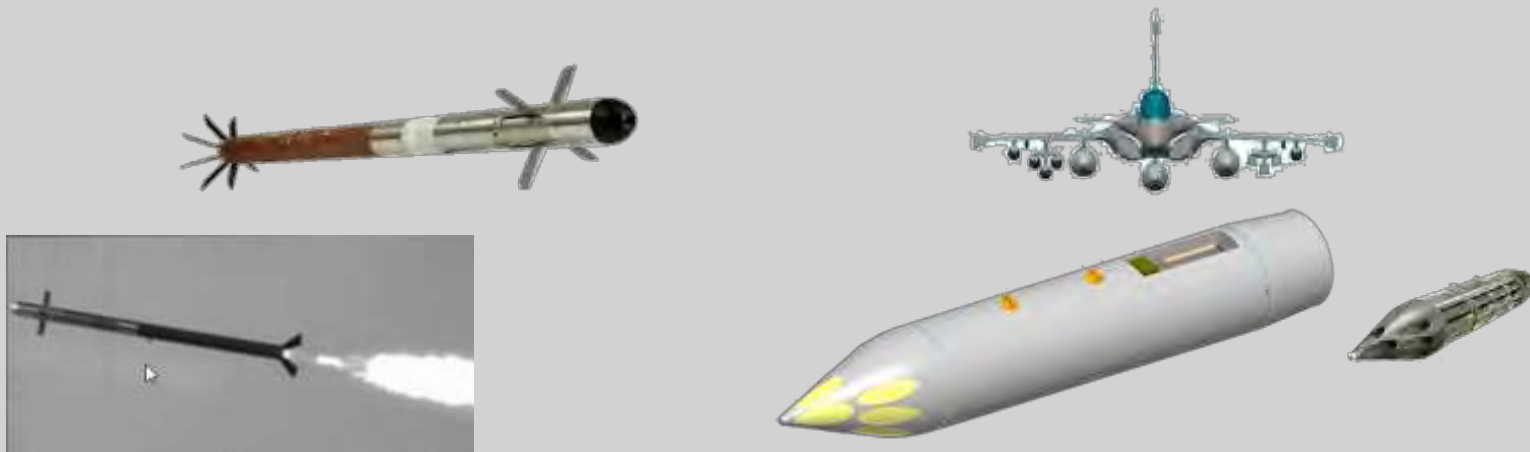


- Prevent enemy to reuse the rocket as improvised weapon or IED

# Future developments

## Rocket System and Fuze

- Digital electronics and inductive setting features provide growth potential and capabilities to deal with further rocket system developments, e.g.
  - Advanced Guided Rocket development (TDA programme)
    - Capability to transmit additional data and mission parameters, eg. Laser code, etc..
  - New generation of warhead for rockets
  - Transposition of Tiger helicopter launcher to fixed-wing aircraft integration
  - Advanced Rocket Launcher for rotary-wing or fixed-wing aircraft





- Due to its inductive fuze setting and communication techniques, the 68mm Rocket System provides the Tiger attack helicopter with unmatched operational benefits:
  - Enhanced terminal effect on target
  - Better operational flexibility
  - More reliability and safety
- New trends in modern warfare highlight new operational needs. This concerns air-to-ground rockets as well as all other weapons and ammunition
- The fuze is the main contributor to the munition's performance. New weapon evolutions relies on progress in fuze capabilities and technologies as well as in fuze integration in the weapon systems
- The fuze designer/producer has a key role in the development of smart weapons



# Thank You

**Max PERRIN**

**Chief Technical Officer**

**[max.perrin@junghans-microtec.de](mailto:max.perrin@junghans-microtec.de)**

**[max.perrin@junghans-t2m.fr](mailto:max.perrin@junghans-t2m.fr)**

# New Data Recorder for Gun Launch and Impact Test with Options for Built-in High G Accelerometers and Angular Rate Sensors



Stephen Pruitt

steve.pruitt@dtsweb.com

May, 2011



# DTS Introduction

- Data recorders and sensors for high shock testing
- Founded in 1990 by three test Engineers
- Small US private corporation with 55 staff members in 6 offices worldwide
- **90+% of customers do “must collect data” testing**
- Key DTS staff have over 100 years of combined high shock test experience



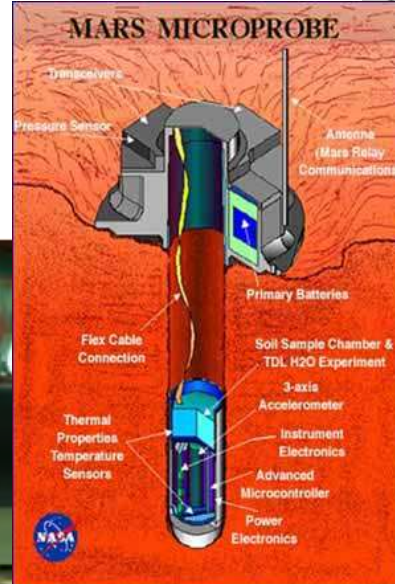
# DTS Introduction – Customers





# Applications for DTS Products

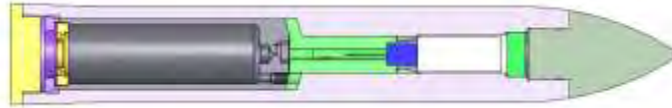
- Data recorders for Manikin and cadaver test
- Vehicle and soldier blast event
- Ejection seat drop tower and rocket sled
- Aircraft/spacecraft flight and crash test
- Hard target recorders





# Applications and Shock

- Hard Target Recorder



100,000 g

1 Msps

- Gun Launch



20,000 g

100 Ksps

- Military Blast



5,000 g

- Vehicle Crash Safety



500 g

20 Ksps

- Motorsports



100 g

5 Ksps

Shock

Sample  
Rate

# Data Acquisition History

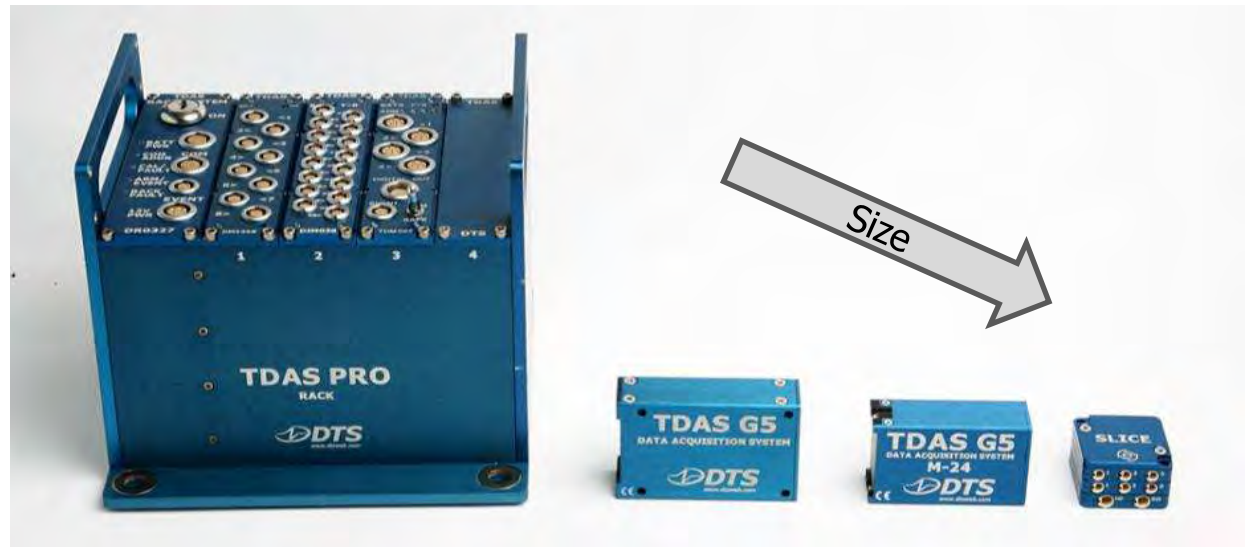
1980s

Amplifiers  
Tape Recorders  
and  
Oscillographs



1990s to  
Present

Self-contained  
Data Recorders



# Technical Terms

- **DAS:** Data Acquisition System, includes analog electronics for sensor inputs, digital conversion and non-volatile memory
- **Sensor or Transducer:** converts physical world to analog or digital voltages
- **ADC:** converts analog signals to digital data, usually 12 or 16 bit resolution
- **Sampling Rate:** how fast ADC samples each channel (sps)
- **Bandwidth:** analog frequency content of data (Hz, usually expressed as -3dB point filter roll-off)
- **AA Filter:** anti-alias filter, determines bandwidth

# SLICE HG



- Based on DTS SLICE data recorder technology
- Eglin Air Force Research Lab ASPIRE Program
  - Phase I and Phase II SBIR, ~Jan 2009 to March 2011
  - Develop 50+ Kg recorder
- DTRA Hard Target Recorder
  - Phase I SBIR, ~Mar 2010 to Dec 2010
  - Develop 100+ Kg recorder
- Also have worked with Sandia Labs and China Lake
- Current contract with Army to up sample rate to 1 Msps/chan, production in 2012

# SLICE Overview

- Two package options, same electronics:

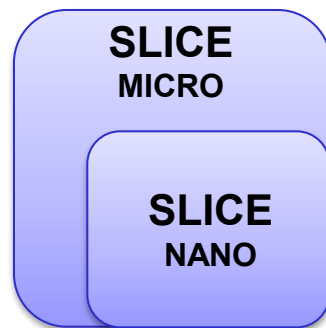
- **SLICE NANO**

- 26 x 31 mm footprint
- Circular connector inputs
- For tight space or embedded applications

- **SLICE MICRO**

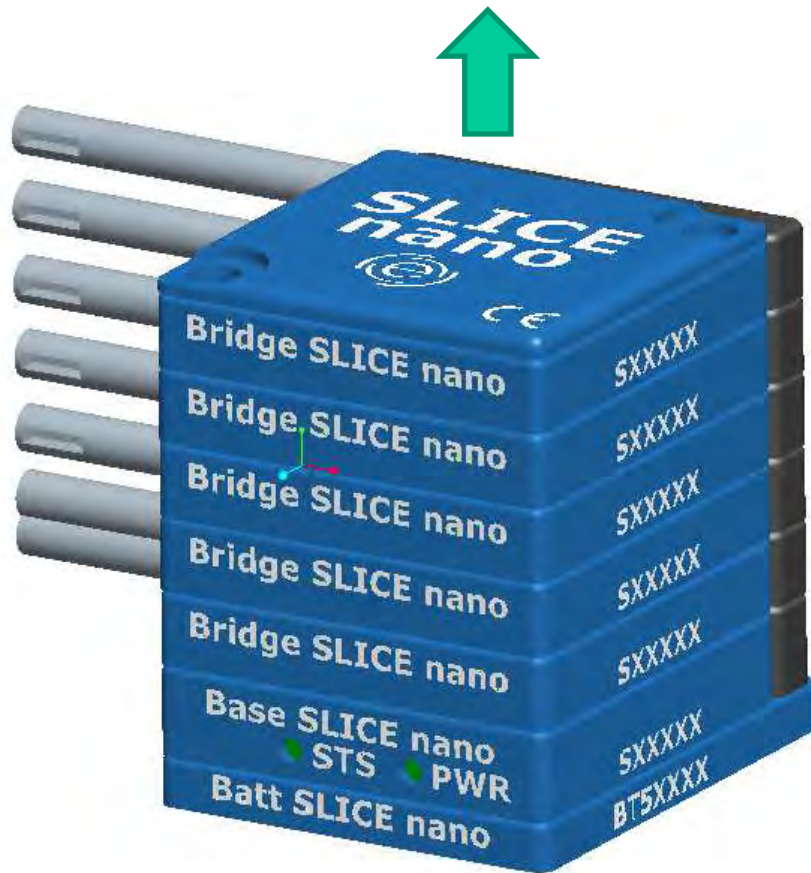
- 42 x 42 mm footprint
- Circular connector inputs

Relative Size



# SLICE Modularity

Up to 8 sensor SLICEs per STACK  
(24 channels)



## Bridge SLICE

- 26 x 31 x 5.5 mm
- 3 channels, 16 bit/chan
- 9-poles of Butterworth filter, adjustable 1 to 40 KHz
- 5V sensor excitation
- Auto offset and shunt

## Base SLICE

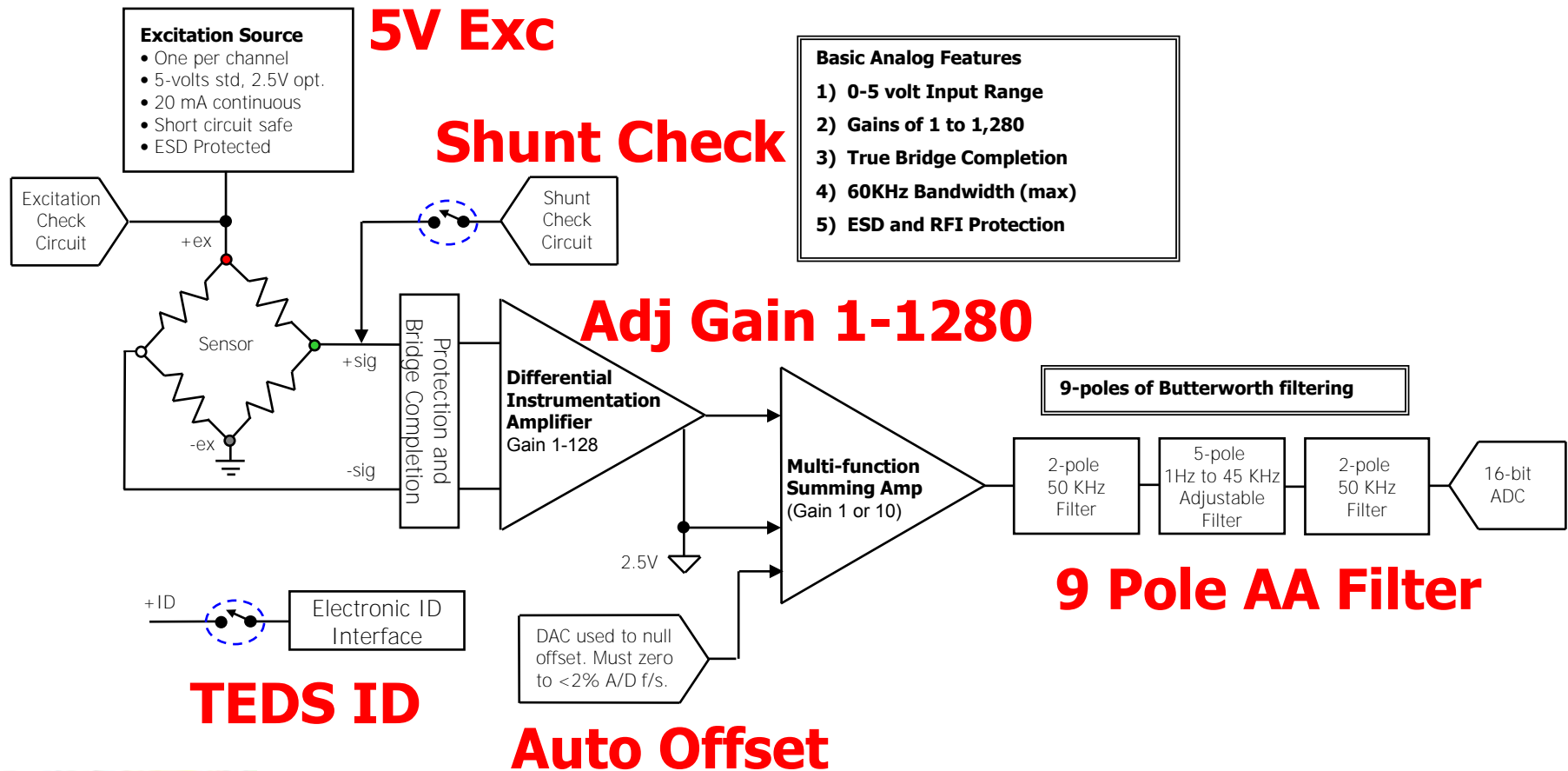
- 26 x 31 x 6.5 mm
- USB 2.0 plus USB hub
- 7 GB Flash memory
- Up to 120 Ksps/chan
- 1 Msps coming in 2012
- Standard 5 Kg shock
- HG packaging to ~50 Kg

Emergency Backup Power,  
up to 3 minutes



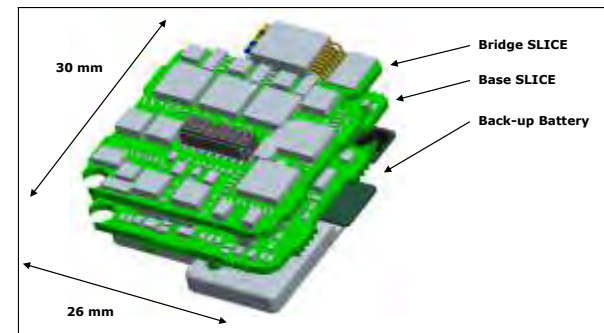
# SLICE Bridge – Sensor Interface

Piezo-resistive, strain gauge or voltage inputs



# SLICE HG – General Specs

- Uses standard SLICE PCBAs (1 Base SLICE, 1 Bridge SLICE, 1 Battery SLICE), packaged in two stage potting process
- 3 channels, 120 Ksps/chan
- 40 KHz bandwidth, 9 pole hardware AA filters
- 7 Gbyte non-volatile flash memory = > 2 hours
- Backup power source for  $\geq 3$  minutes
- Every unit tested at DTS to > 20 Kg, 0.1 msec



# SLICE HG – Arming and Triggering

## Arming Options

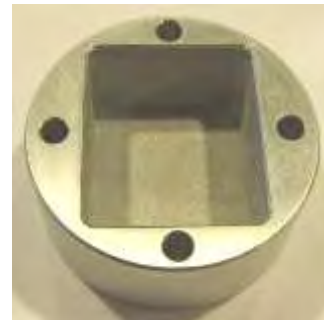
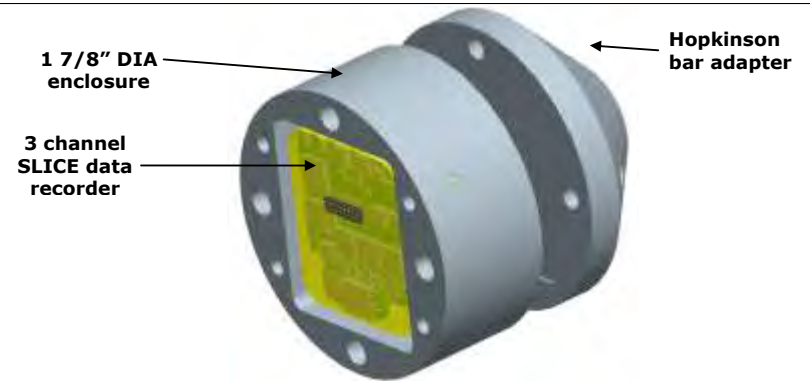
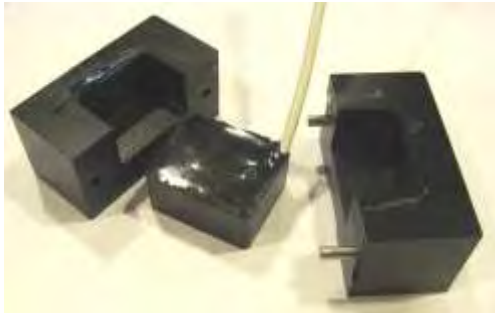
- Arm on Power up – wait for Start signal
- Start Recording on Power up

## Triggering Options

- Start signal on separate 0-5V input
- Event ( $T=0$ ) on Contact Closure or Level Trigger
- Over 2 hours of data collection
- Non-volatile flash memory

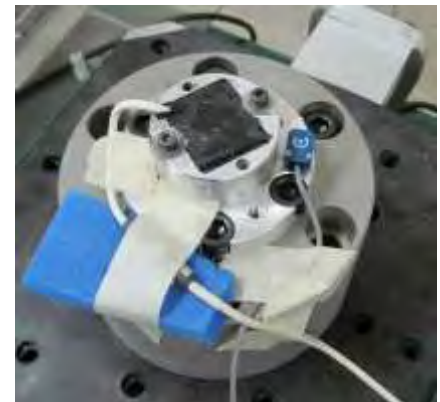
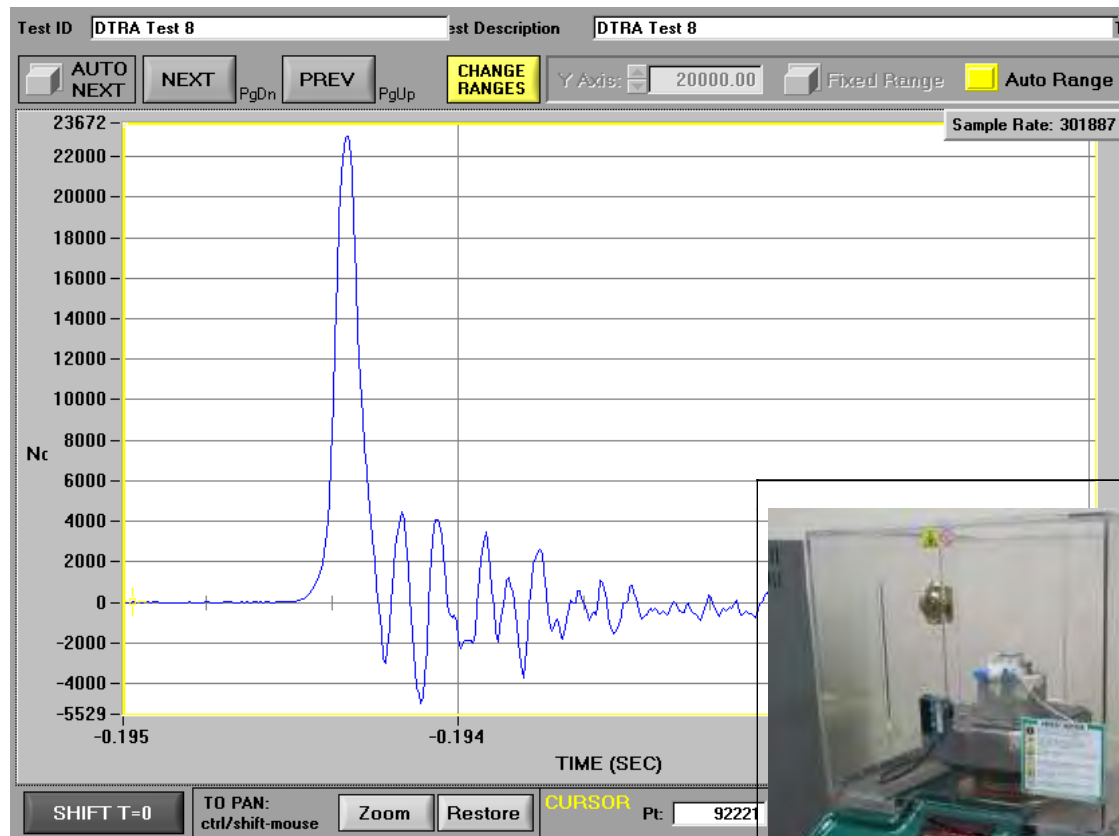
# SLICE HG - Packaging

Two stage, hard then software potting

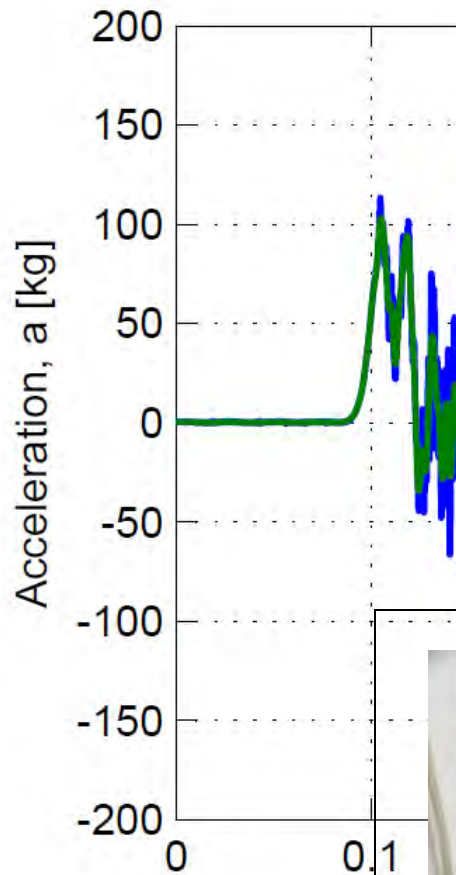


# SLICE HG – Shock Testing

Tested at DTS to  $\sim 23,000$  g's, 0.1 msec



# SLICE HG – Shock Testing



Tested at Endevco on Hopkinson Bar, ~80,000 g's, 0.04 msec





# SLICE HG – Shock Testing

---

- China Lake has run sled tests for missile impact with success
- 6 SLICE HG units delivered to Eglin AFB for test
- SLICE HG at Sandia for test

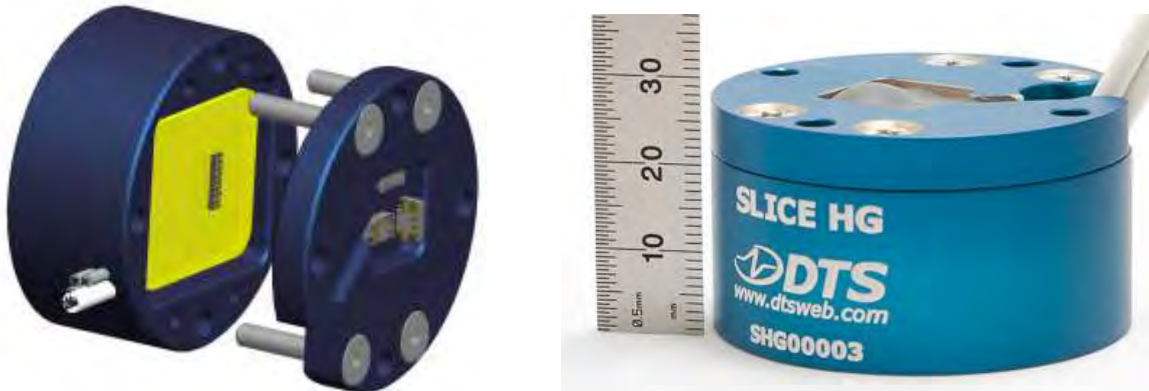
# Shock Hardening Considerations

For 20 Kg+ g environments, DTS products incorporate these features:

- **Large IC's on PCB epoxied down before soldering**
- Other larger components have adhesive applied
- Crystal time base oscillators used, up to 100K g rating
- Other high shock rated components used as required
- Visual and X-Ray inspection used on PCB assemblies and solder joints
- PCB assemblies are potted in a two-stage potting process
- All final products are 100% shock tested to 20+ Kg to verify robust operation before delivery to customer

# SLICE HG – Package Sizes

- 1.875" DIA x 1.05" (47.6 x 26.5 mm)



- 1.25" DIA x 1.67" (31.8 x 42.5 mm)



# SLICE HG – Configurations

Option for embedded 3 axis accelerometers from various manufacturers or an angular rate spin sensor



PCB 3501 60 Kg accels

# SLICE HG – Configurations

- Up to four 3 chan. units can be chained (12 chan.)
- External power: ~12V at 250 mA per 3 channel unit
- Units are independent, standalone. The failure of one does not cause failure of another
- Various options for triggering and monitoring



# SLICE HG – Availability

- In production
- Price is ~\$15,000 per 3 channel unit
- Additional cost of built-in accelerometer or ARS options depend on sensor manufacturer/model
- Typical lead time is 8 weeks
- Export status is pending review
- DTS offers 24/7 technical support and on-site training



# New Data Recorder for Gun Launch and Impact Test with Options for Built-in High G Accelerometers and Angular Rate Sensors



Stephen Pruitt

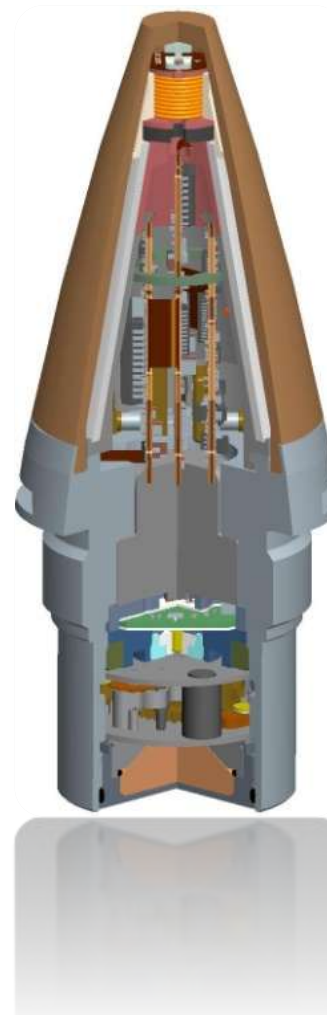
steve.pruitt@dtsweb.com

May, 2011



# Multi-Function Fuze Capability Against High Speed Mobile Water Attack Craft

55th Annual NDIA Fuze Conference  
 Presenter: James Ring  
 ATK Propulsion & Controls



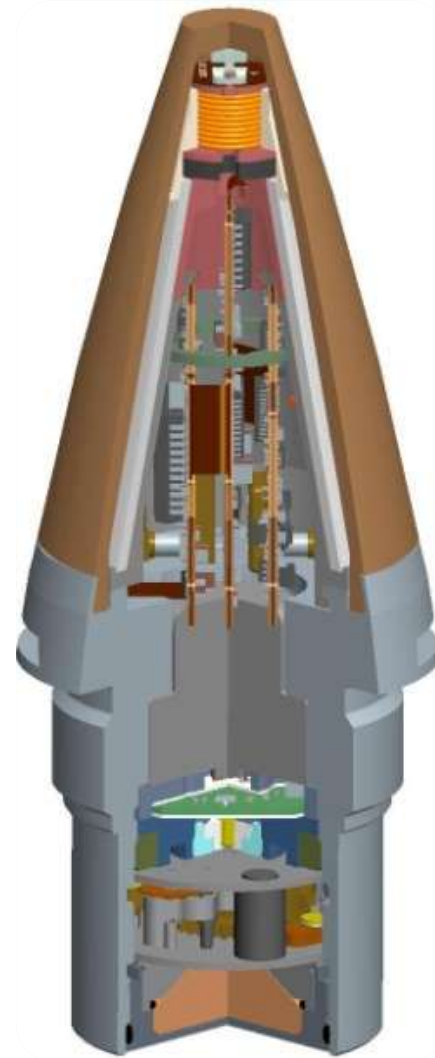
Approved for Public Release, May 18th, 2011 #367-11,  
 Statement A, Public Release, distribution is unlimited, 22 CFR 125.4(b)(13) applicable.



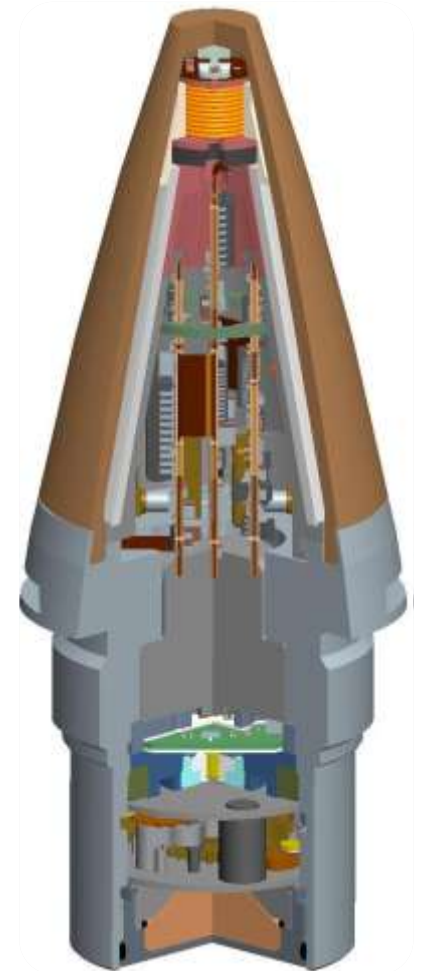
# Presentation Agenda



- **Functional Overview**
- **Design And Production Background**
- **Major Components & Subassemblies**
- **Fuzing Concept**
- **Benefits vs. Today's 5" Gun Solution**
- **Performance Results**
- **What's Next**
- **Summary**
- **Acknowledgements**

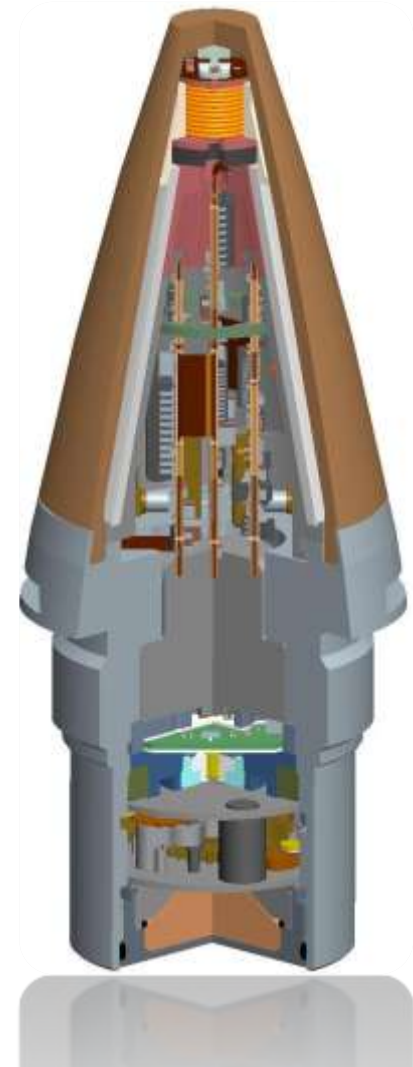


- MK419 is a Multi-Function Fuze (MFF) for the Navy 5" Gun
- Inductively Set by the Navy's MK 34 electronic fuze setter
- Selectable Operational Modes
  - Air Proximity (AIR)
  - Height of Burst (HOB)
  - Autonomous (AUTO)
  - Electronic Time (ET)
  - Point Detonate (PD)
- Primary safety mechanism is the MK 60 Safe and Arm
- Flight power is provided by Lithium Reserve Battery
  - Activated by setback and spin
  - Provides electronics power for >105 seconds



MFF Is A Single Fuze Solution That Supports All Required Modes Of Operation

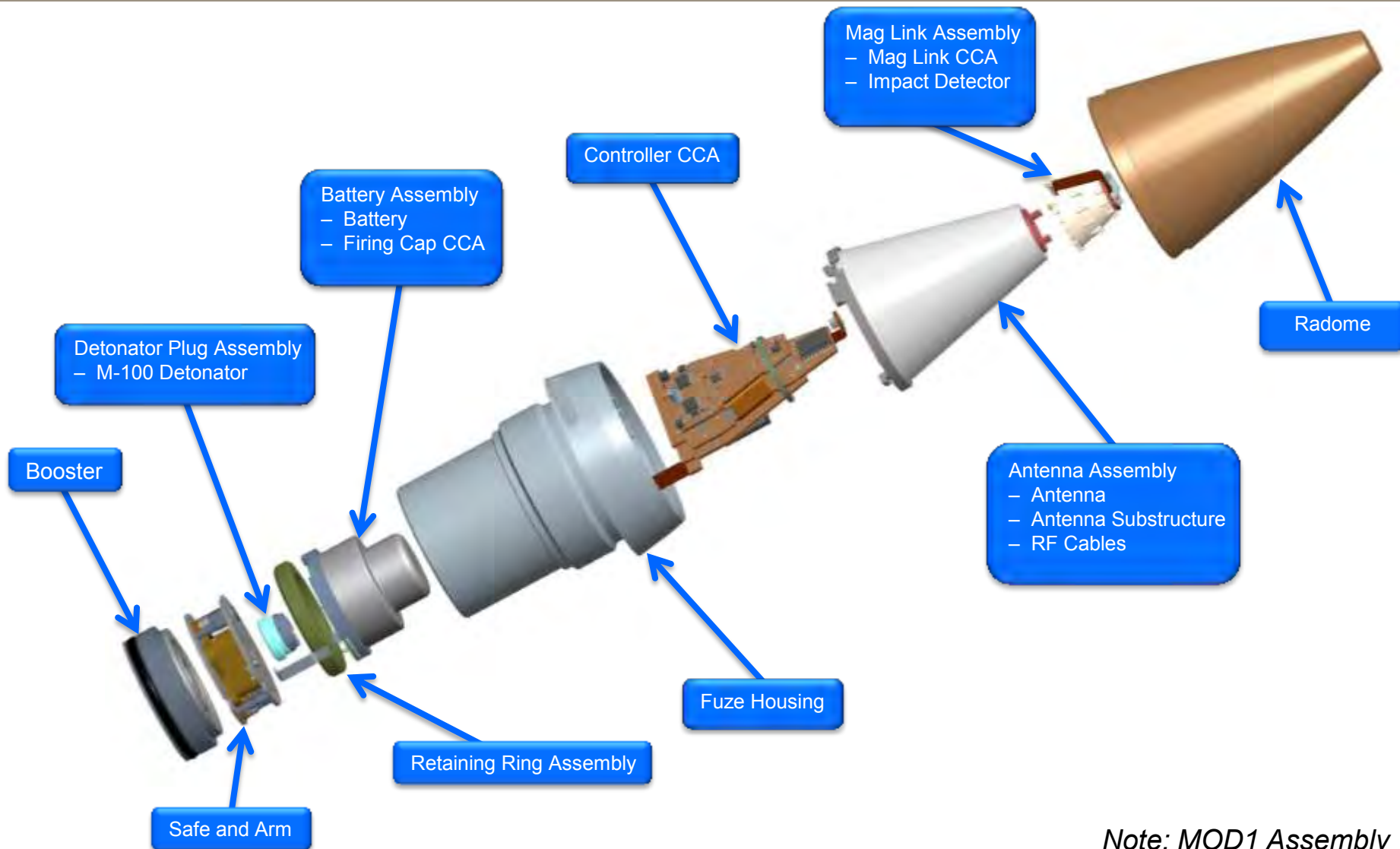
- MOD0 Design (~1980s to 2001)
  - Early design efforts began in the late 1980's by Motorola
  - Transitioned to ATK in 1998
  - Qualification in 2000
- MOD0 FAAT And Production (2001 to 2004)
  - First Article Acceptance Testing (FAAT) in 2001
  - Produced at ATK production facility
- MOD1 Production Improvement Program (PIP) (2009 to 2011)
  - Reduced AUPC
  - Exceeded functional capability
- MOD1 Production Planned for 2011
  - Planned to be manufactured at ATK's production facility



MOD1 Simplified Design and Assembly  
Increases Reliability, Lowers Cost, and Improves Performance



# Major Components & Subassemblies



*Note: MOD1 Assembly*

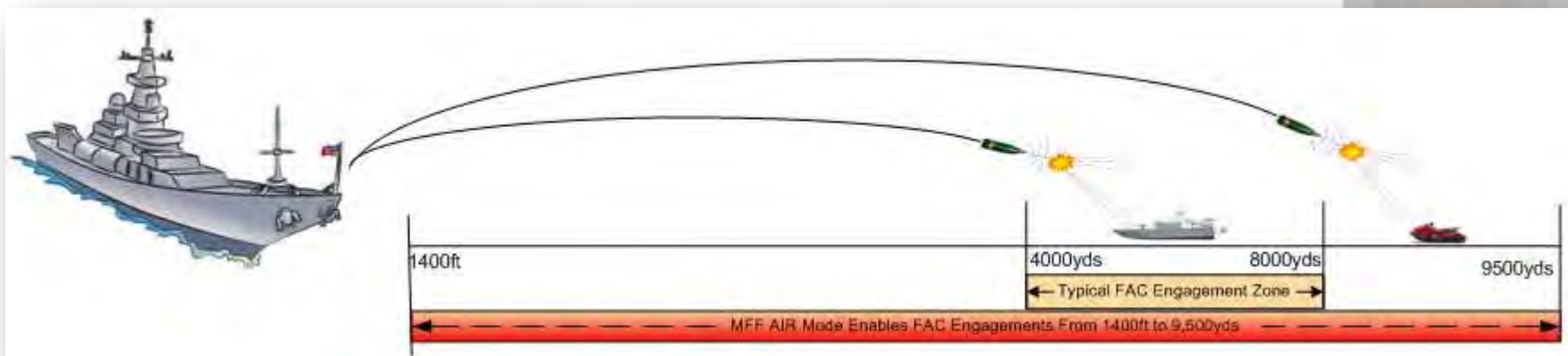
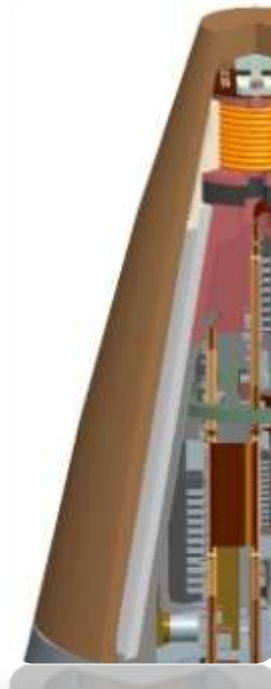
**MOD1 Updated Subassemblies Greatly Simplify Assembly Operations**



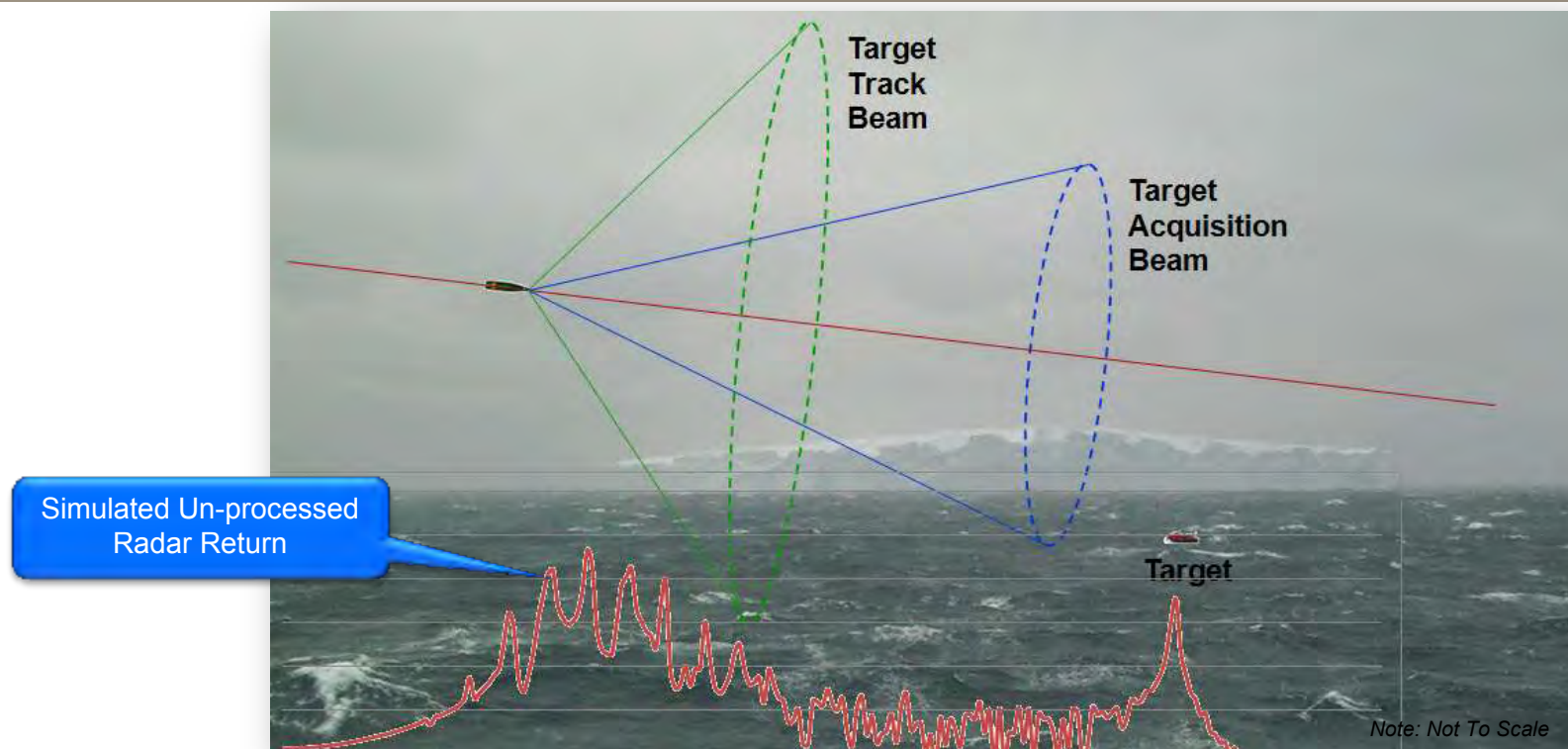
# Fuzing Concept



- Fast Attack Craft (FAC) provide serious threats to Navy ships
- Navy 5" Gun with **currently deployed** MOD0 and new MOD1 MFF fuzes
- **"Use-As-Is"** existing MFF AIR Mode fuzing capabilities
- Engagement range from 1400ft to 9500 yards
- Engagement of very small Radar Cross Section (RCS) targets
- Ability to engage targets in various sea states



MFF Provides Navy With Immediate Solution To FAC Threats



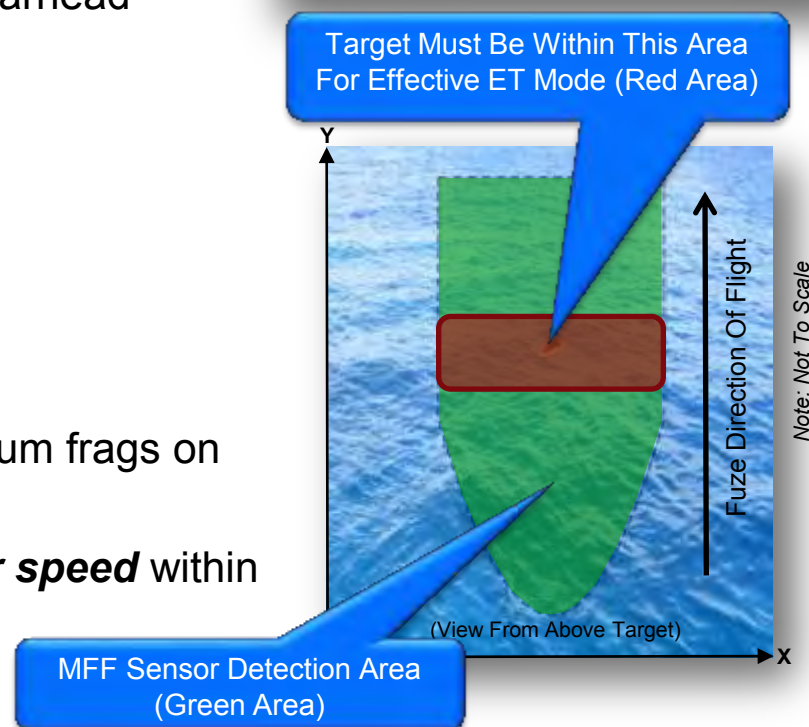
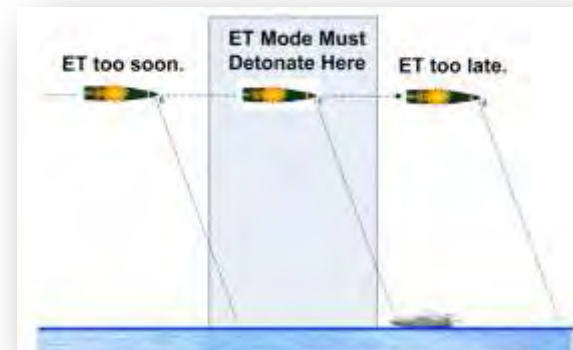
- MFF scans water for targets without detonating on sea clutter in various sea states
- Target Acquisition Beam (search mode)
  - Signal processing dynamically focuses radar toward expected target area
  - Filters out sea clutter to enable fuze to operate very close to water
- Target Track Beam (locked and tracking mode) tracks target to optimum burst angle

MFF Dynamic Signal Processing Filters Sea Clutter And Detects Valid FAC Target

# Benefits vs. Today's 5" Gun Solution



- Electronic Time (ET) Mode Against FAC Targets
  - High Explosive with high velocity fragments
  - Current 5" artillery FAC counter measure
  - Fuze must detonate within a small time window to hit FAC target.
  - Small errors will result in a miss or reduced warhead fragments on target:
    - Electronics timing error
    - Gun Weapon System error
    - Change in target direction or speed
- MFF AIR Mode Against FAC Targets
  - High Explosive with high velocity fragments
  - Detonates at **optimal fuzing angle** to maximum frags on target
  - Adapts when FAC **changes direction and/or speed** within sensor detection area



MFF Detonates At Optimal Fuzing Angle To Maximize Warhead Effectiveness

# Performance Results

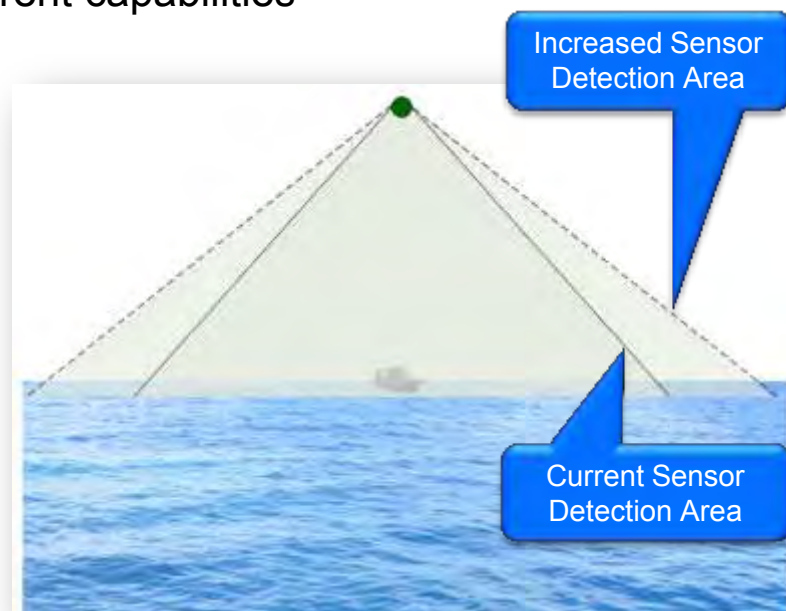


- Dahlgren, Potomac River, in November 2004 (MOD0)
  - Objective: Detect and fuze on small boat targets
  - Functioned and localized fragment pattern on target
  - Initial assessment of sensor detection distance threshold
- Dahlgren, Potomac River, in June 2007 (MOD0)
  - Objective: Further evaluation of MFF against boat targets
  - Functioned and localized fragment pattern on target
  - Boat targets were destroyed on first shot
- Dahlgren, Potomac River, in Dec 2010 (MOD1)
  - Objective: Verify MOD1 Sea Clutter Rejection feature
  - Sea Clutter Rejection performance exceeded expectations



MFF Successfully Detected And Fuzed On Small Boat Targets

- Further characterization in various RCS targets in various sea states
- Navy system operational analysis of 5" gun using MFF AIR mode
- Define requirements (ie: RCS, sea states, ect..)
- Qualification testing
- Develop enhancements to optimize and enhance current capabilities
  - Increase maximum sensor detection area
  - Optimize target validation algorithm
  - Optimize performance in various sea states
  - Optimize for maximum range of 5" gun
  - Implement ET Mode as the backup mode

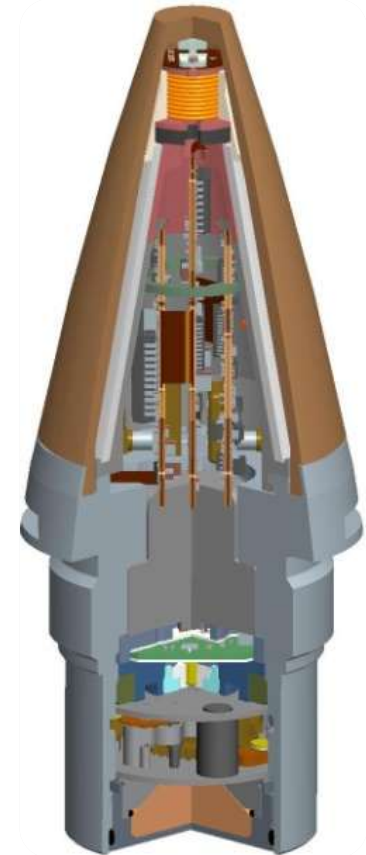


*Note: View From Aft*

Future Enhancements Will Optimize Effectiveness For Tomorrow's FAC Threat



- MFF has **immediate** defeat capability against FAC targets
- Ballistic testing has **verified performance**
- MOD1 has **improved** performance and capability
- Need to qualify and characterize MOD1 against FAC targets
- Quick-turn enhancements can **optimize** current capability
- MOD1 production line is ready **today** to build additional fuzes for this effort



MFF Provides An **Immediate And Effective** Solution To FAC Threats





## Thanks to:

Mr. Richard Chapman – NSWC-DD Project Manager

Mr. Marty Davis – ATK Program Manager

## Fuze Power Quo Vadis?



55<sup>th</sup> Fuze Conference  
May 26<sup>th</sup>, 2011, Salt Lake City, UT  
Harald Wich

# Outline

- ◆ History
- ◆ Requirements
- ◆ Alternative Power Sources
- ◆ Liquid Reserve Batteries
- ◆ Quo Vadis – Fuze Power ?



# Some History

- ◆ First time Electric Power required for Proximity Fuzing in the early 1940's
  - some earlier Patents e.g. US1,769,203 in the 30's
  - Pye Ltd in GB and USNAVY in US – Mk 32 later on Mk 45, Mk 53

July 1, 1930. J. P. BUCKLEY 1,769,203  
HELICOPTER  
Filed April 30, 1929 3 Sheets-Sheet 3

- first “Reserve Type Battery” US1,658,142

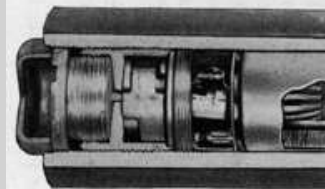
⇒ 70 years of history



- ◆ My own experience

- piezoelectric setback generators
- air – driven alternators
- thermal battery

⇒ dates back 35 years



# Requirements general

- ♦ Volume (size) and Weight
- ♦ Power = Voltage x Current
  - ↓ ↓ ↘  $\mu\text{A}$  to 100's of mA
  - ↓ ↘ a mere 2 V up to 10's of V
  - ↘  $\mu\text{W}$  to W
- ♦ Lifetime < 10 s to > 600 s
- ♦ Energy =  $\int_{t=0}^{t_{it}} V(t) * I(t) dt$   $\mu\text{J}$  up to J
- ♦ Rise time ms up to 100's of ms
- ♦ Reliability 99.xxxx%
- ♦ Storage Life 10 years +
- ♦ Cost nil

# Requirements

## ♦ Fuze Categories

classical artillery

PD

Detonator

- ⇒ 100  $\mu$ J M100
- ⇒ 5 mJ Silicon Bridge Initiator
- ⇒ 50 mJ 1 W/1A
- ⇒ 100 mJ LEEFI

⇒ usually a Factor of 3 – 5 (10) in the firing circuit !



# Requirements

- ◆ Fuze Categories  
classical artillery

PD  
SD

Det  
Det + Timer

↘ 2  $\mu$ W e.g. digital watch

# Requirements

- ◆ Fuze Categories

classical artillery

PD

Det

SD

Det + Timer

ET

Det + programmable Timer

↙ 600  $\mu$ W e.g. RFID-Circuit

# Requirements

- ◆ Fuze Categories

classical artillery

PD

Det

SD

Det + Timer

ET

Det + programmable Timer

PX

Det + prog. Timer + TX/RX

↘ some 100 mW's

# Requirements

## ♦ Fuze Categories

classical artillery

PD

Det

SD

Det + Timer

ET

Det + programmable Timer

PX

Det + prog. Timer + TX/RX

CCF

Det + prog. Timer + TX/RX + Control Power

↙ some W's

# Requirements

## ◆ Fuze Categories

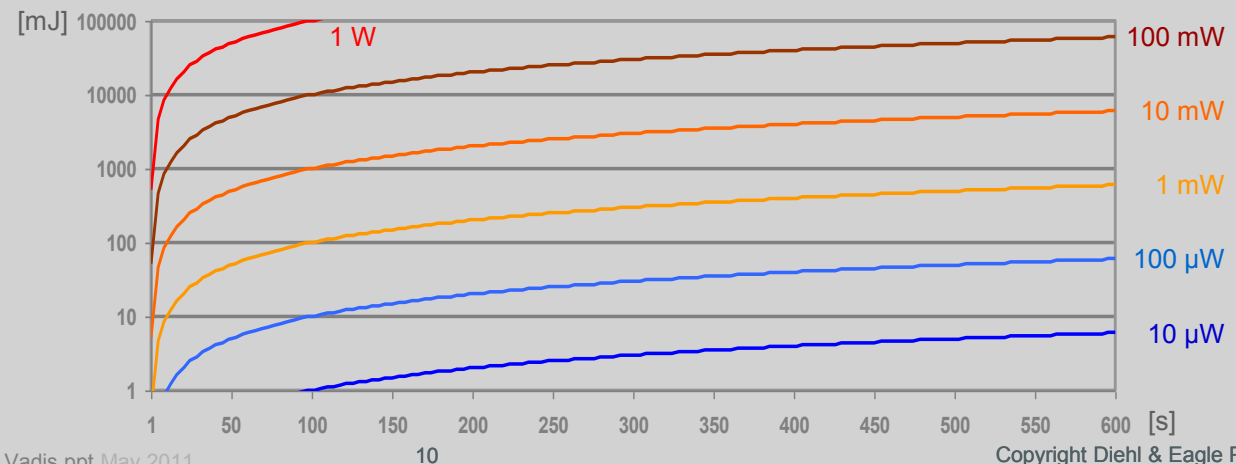
classical artillery

PD	Det
SD	Det + Timer
ET	Det + programmable Timer
PX	Det + prog. Timer + TX/RX
CCF	Det + prog. Timer + TX/RX + Control Power

## ◆ Operating Times

short	$\leq 10 - 20$ s	direct fire
medium	$< 100$ s	indirect fire Mortars
long	$< 200$ s	indirect fire Arty 105/155 mm
x-long	up to 600 s	gliding and/or powered

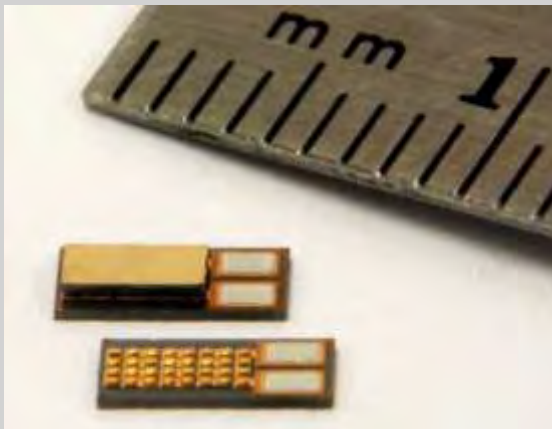
## ◆ Energy



# Alternative Energy Sources

- ♦ Where could the energy come from

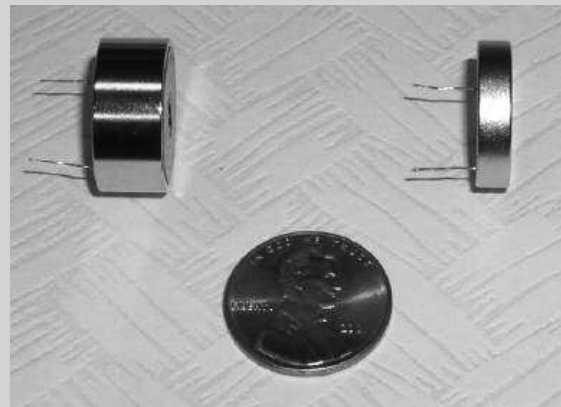
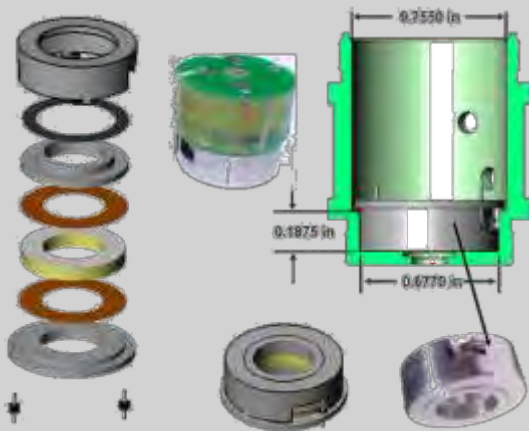
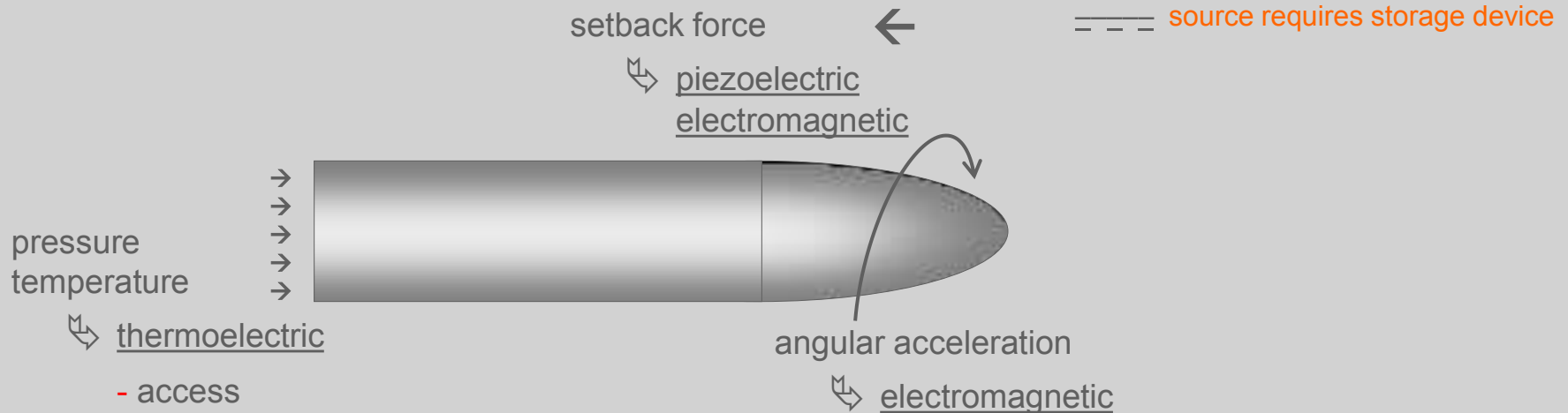
--- source requires storage device





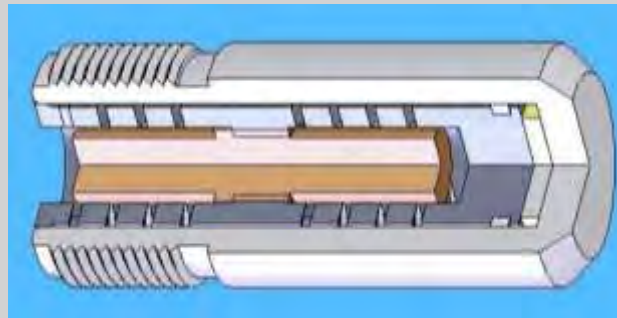
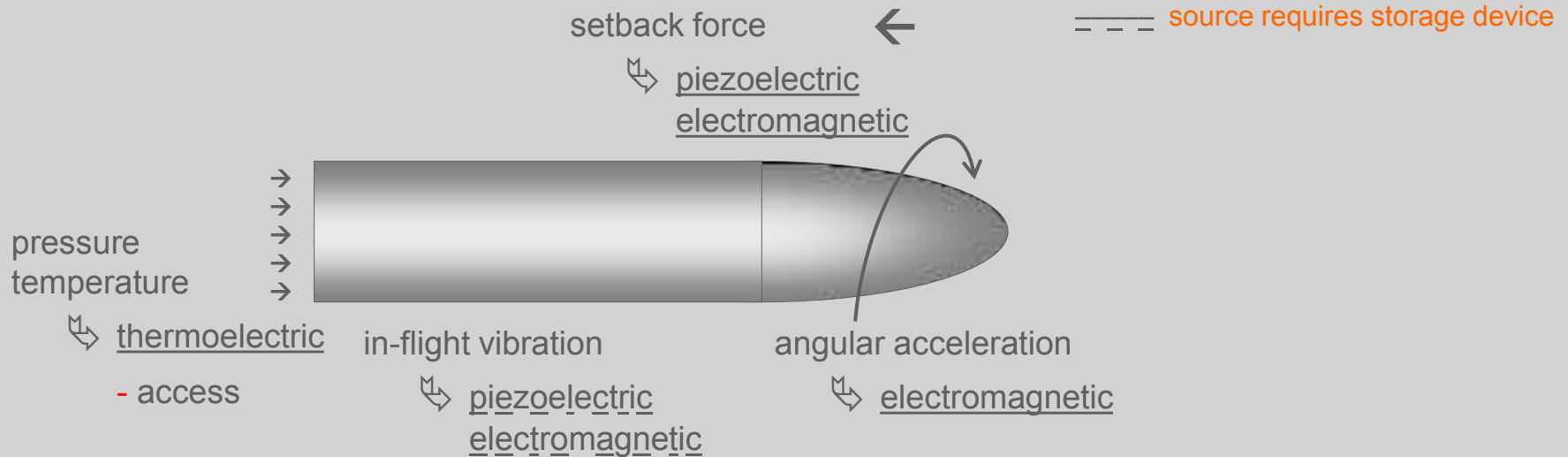
# Alternative Energy Sources

- Where could the energy come from

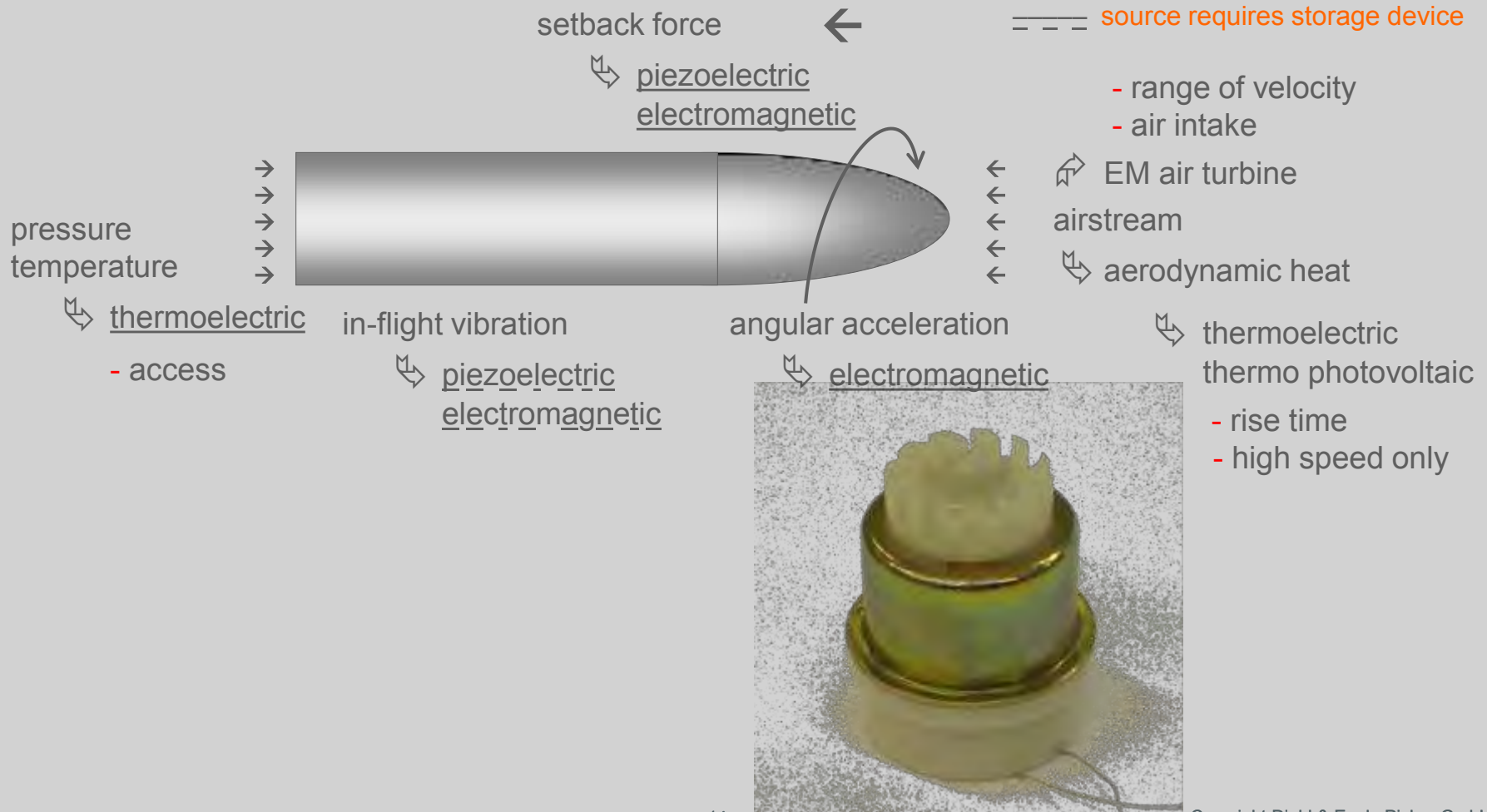


# Alternative Energy Sources

- ♦ Where could the energy come from

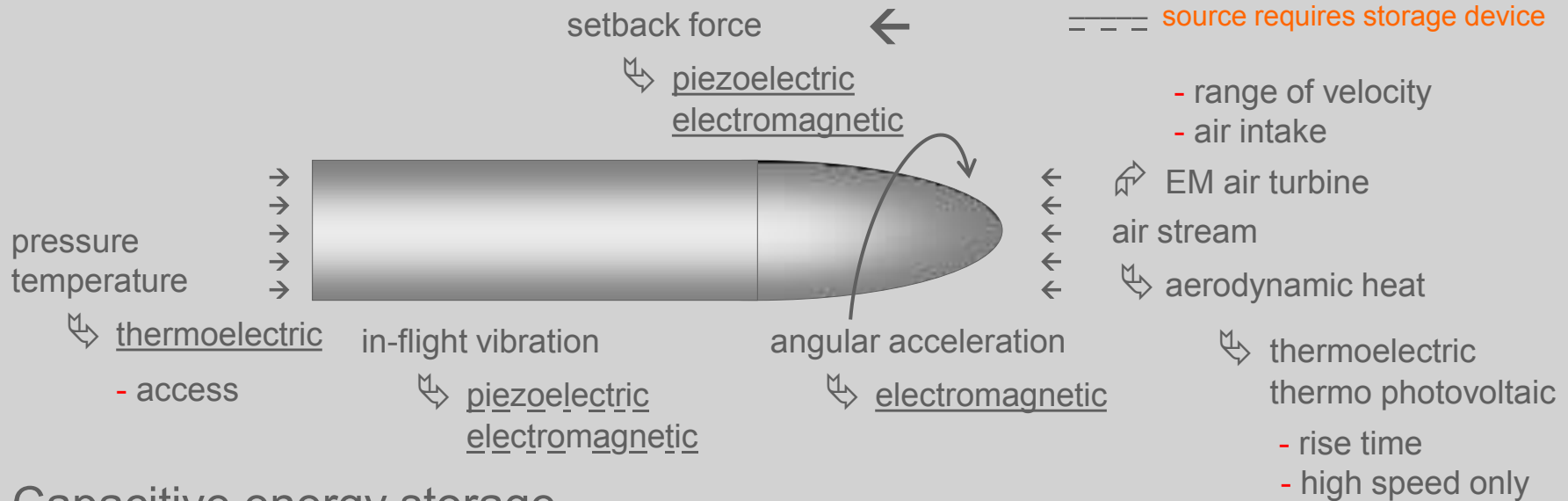


- ◆ Where could the energy come from



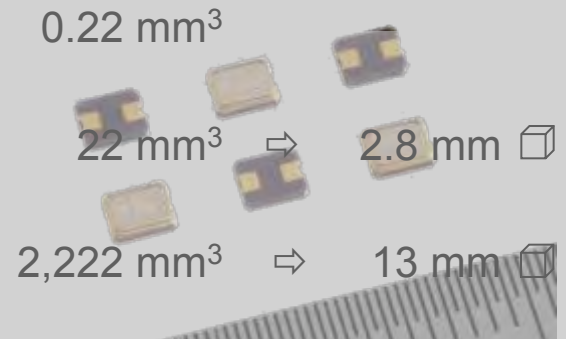
# Alternative Energy Sources

## ♦ Where could the energy come from

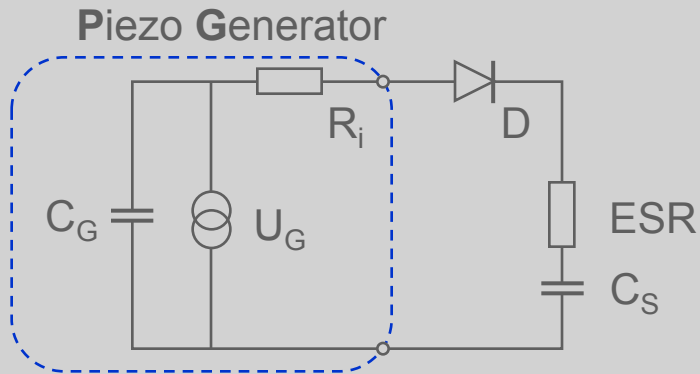


## ♦ Capacitive energy storage

storage of	1 mJ	@ 10 V ⇔	20 $\mu$ F
		@ 30 V ⇔	2.2 $\mu$ F
	100 mJ	@ 10 V ⇔	2000 $\mu$ F
		@ 30 V ⇔	220 $\mu$ F
	10,000 mJ	@ 10 V ⇔	0.2 F
		@ 30 V ⇔	0.022 F



## ♦ Charging and discharging the capacitor



PG-Voltage proportional to pressure (= acceleration)

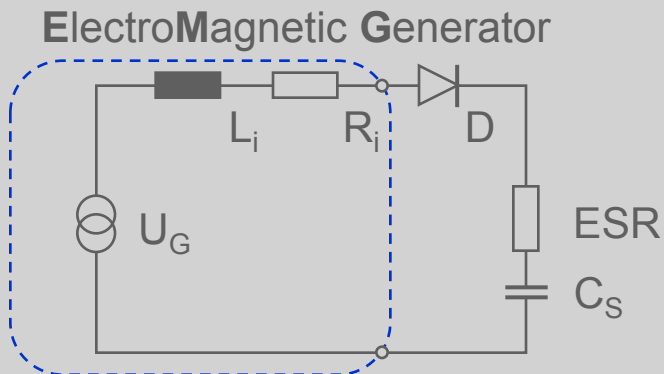
↳ peak voltage @ peak pressure  
ms only ⇒ high currents, matching losses

e.g. storage of 10 mJ    @ 10 V ⇒ 200 μF ⇒ 1.1 A (2 ms)  
                                 @ 30 V ⇒ 22 μF ⇒ 0.33 A (2 ms)

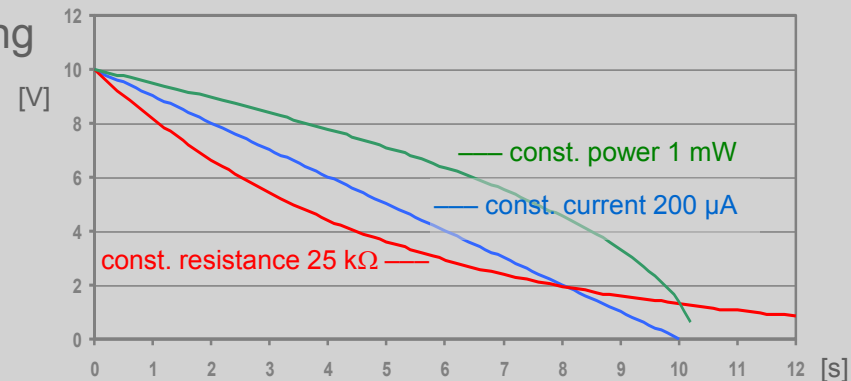
EMG-Voltage proportional to # of turns/inductance

↳ natural frequency  $f_r = (2 * \pi * \sqrt{L_i * C_s})^{-1}$

e.g. storage of 10 mJ    @ 10 V ⇒ 200 μF ⇒ 112 Hz (10 mH)  
                                 @ 30 V ⇒ 22 μF ⇒ 339 Hz (10 mH)



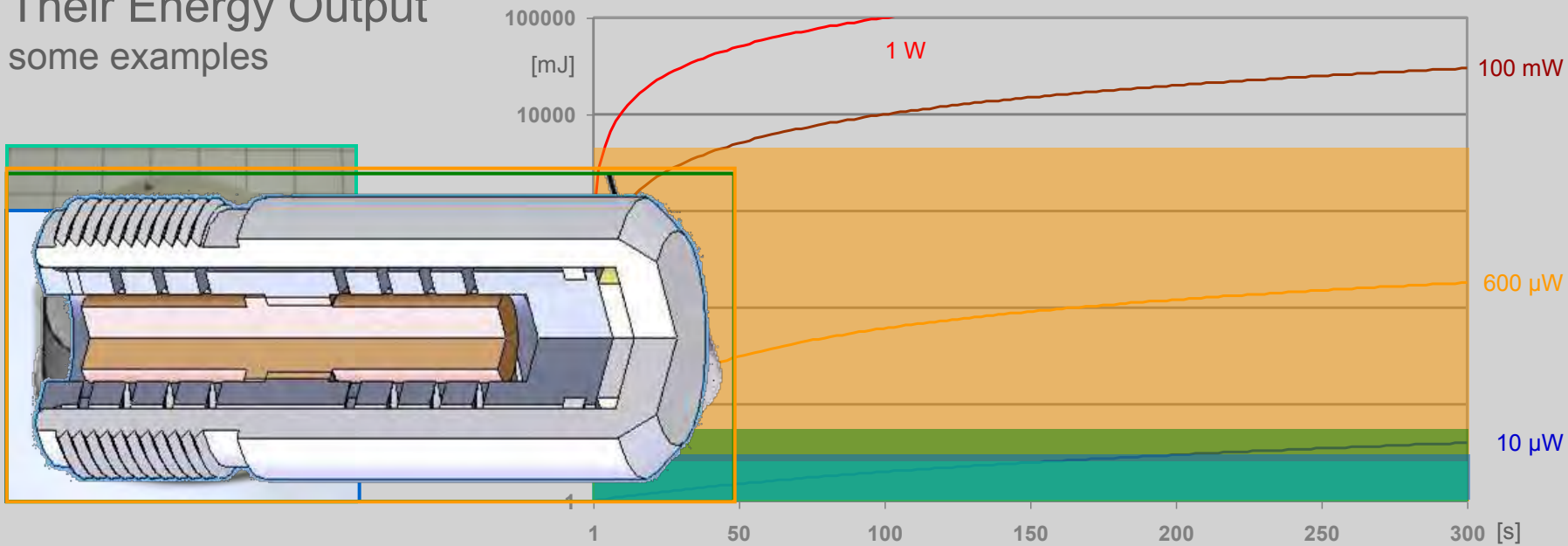
Discharging



**No constant Voltage during discharge!**

# Alternative Energy Sources

- ◆ Their Energy Output  
some examples



- ◆ My Conclusion

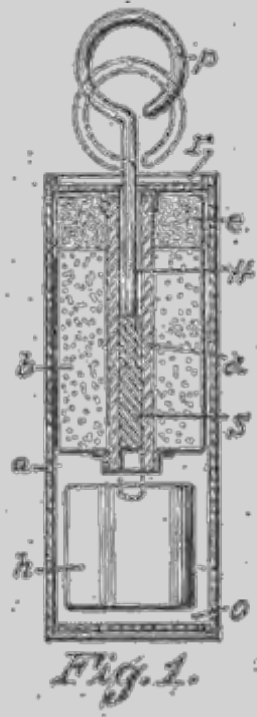
- no significant improvement of energy generated since 35 years  
limited to
  - low energy pyrotechnics
  - short time of flight
  - simple functions



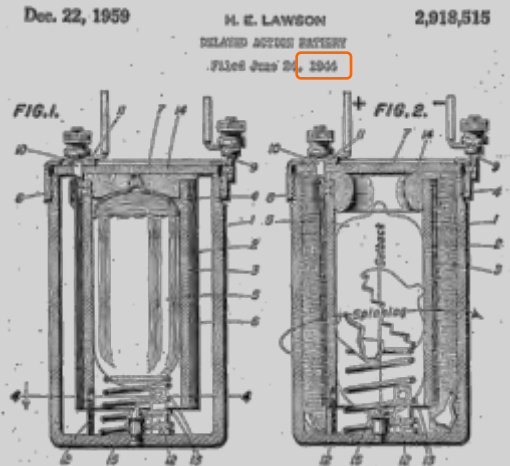
# Liquid Reserve Batteries

## ♦ Legacy

**K. STAMM**  
**ELECTRIC DRY BATTERY**  
Filed Feb. 9, 1925



First Reserve Battery



Fuze Battery



Fuze Battery



MOFA Fuze Battery



SHORT ENERGIZER MK 4 MOD 2  
(LEFT HALF SECTION PLUGGED INTO  
SPIN BREAKER MK 1 MOD C)



LONG ENERGIZER  
MK 5 MOD 2

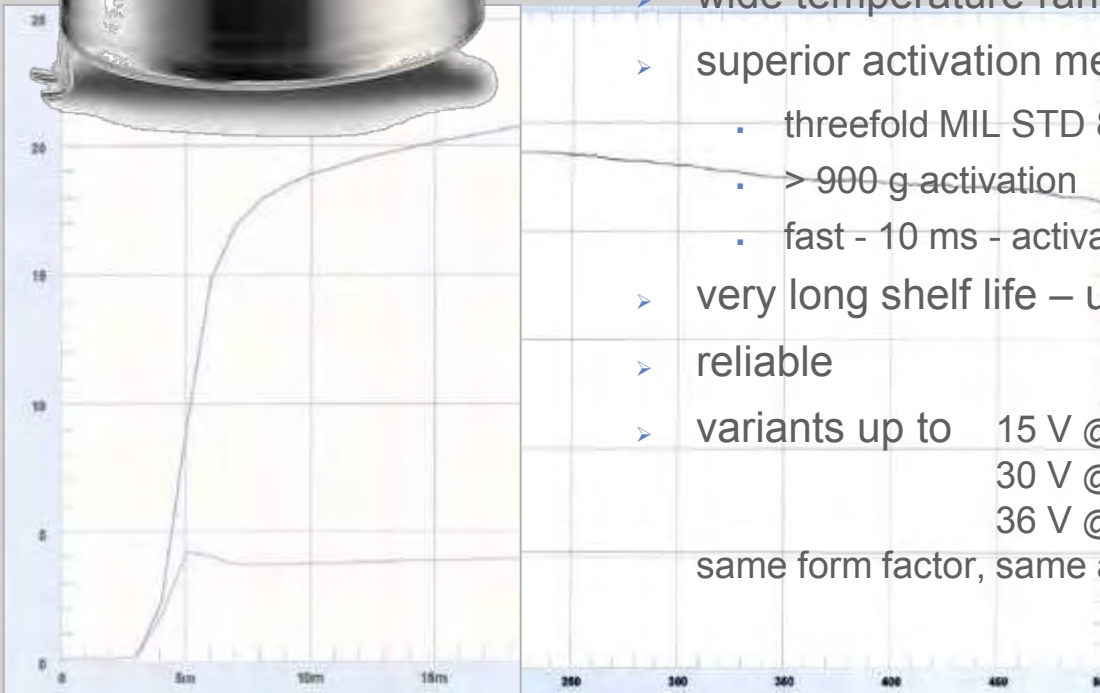


Mk53 Fuze

# Liquid Reserve Battery current

## The workhorse (type 597) Lithium Thionyl Chloride

- most common fuze battery in Europe (European complement to MOFA-Battery)
  - produced in 100 thousand's
  - powerful ( $0.25 \text{ W/cm}^2$  active cell area)
  - wide temperature range  $-46^\circ\text{C}$  to  $+63^\circ\text{C}$
  - superior activation mechanism
    - threefold MIL STD 883 1.5 m drop safety
    - $> 900 \text{ g}$  activation
    - fast - 10 ms - activation under spin environment
  - very long shelf life – up to 20 years
  - reliable
  - variants up to
    - 15 V @ 600 mA
    - 30 V @ 300 mA
    - 36 V @  $< 100 \text{ mA}$
- same form factor, same activation



# Liquid Reserve Battery future

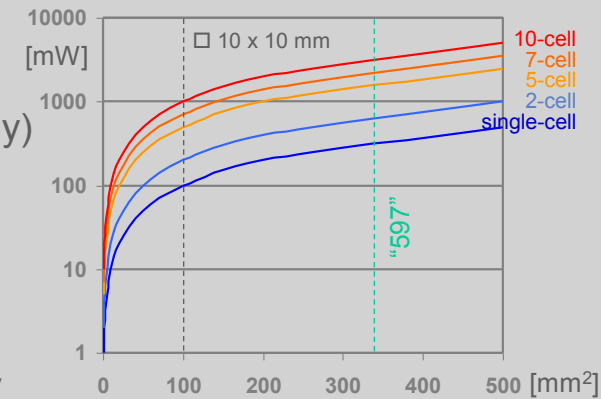
## ♦ How big is their Energy-/Power-Density



— this volume equals **3,000 mJ** (Electrochemistry only)

➤ what's needed for a complete LRB

- Electrochemistry
- Electrolyte separated from Cell Stack



"597"



"762"

- Activation System



"AM"



"AH/AD"

**For low and medium Power a single Cell will be the preferred Solution**

# Small Liquid Reserve Batteries

- ♦ Can be very small whilst maintaining their excellent properties
  - superior Power-/Energy-Density
  - long shelf life
  - wide temperature range
  - excellent reliability
  - low cost
- ♦ Some recent examples

➤ M235



➤ M80



➤ MRB



➤ 40 mm AB



single cell Lithium

multi cell Pb PbO<sub>2</sub>

# Yet a new small Liquid Reserve Battery

- ◆ For small and medium calibre applications



- 12 mm diameter
- 12 mm high
- single cell Lithium Battery
- 3.0 ÷ 3.6 V closed circuit voltage
- up to 50 mA load current
- setback/spin activation mechanism
  - > 7000 g activation
  - fast - < 5 ms - activation under spin environment
- lifetime > 50 s
- wide temperature range -46°C to +63°C
- very long shelf life – up to 20 years
- reliable
- low cost

**Lithium Liquid Reserve Batteries provide superior Energy Density**

**Thank you for your Attention!**

**Any Questions, Comments, Objections, ...**



# Diehl & Eagle Picher in a Nutshell

- ◆ About the company
  - US/German Joint Venture;  
Shareholders are Eagle Picher Technology, Joplin MO and  
Diehl BGT Defence, Ueberlingen GE
  - Located in Roethenbach Germany
  - Thermal- and Fuze-Batteries and Battery Packs
  - R&D and Production of the above Batteries
  - Annual Turn Over > 10 mEur

# Diehl & Eagle Picher Contact

## ♦ How to Contact us

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